NAVAL POSTGRADUATE SCHOOL
Monterey, California

THESIS

FEASIBILITY OF THE TACTICAL UAV AS A COMBAT IDENTIFICATION TOOL

by

Michael P. Farmer

September 2001

Thesis Advisor:	John Osmundson
Thesis Associate Advisor:	William J. Welch

Approved for public release; distribution is unlimited.

Report Documentation Page

Report Date	Report Type	Dates Covered (from... to)
30 Sep 2001	N/A	-

Title and Subtitle Feasibility of the Tactical UAV as a Combat Identification Tool 5. FUNDING NUMBERS	**Contract Number**
	Grant Number
	Program Element Number
Author(s) Farmer, Michael P.	**Project Number**
	Task Number
	Work Unit Number
Performing Organization Name(s) and Address(es) Research Office Naval Postgraduate School Monterey, Ca 93943-5138	**Performing Organization Report Number**
Sponsoring/Monitoring Agency Name(s) and Address(es)	**Sponsor/Monitor's Acronym(s)**
	Sponsor/Monitor's Report Number(s)
Distribution/Availability Statement Approved for public release, distribution unlimited	
Supplementary Notes	
Abstract	
Subject Terms	
Report Classification unclassified	**Classification of this page** unclassified
Classification of Abstract unclassified	**Limitation of Abstract** UU
Number of Pages 129	

REPORT DOCUMENTATION PAGE	*Form Approved OMB No. 0704-0188*

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instruction, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188) Washington DC 20503.

1. AGENCY USE ONLY *(Leave blank)*	**2. REPORT DATE** September 2001	**3. REPORT TYPE AND DATES COVERED** Master's Thesis

4. TITLE AND SUBTITLE: Title (Mix case letters)
Feasibility of the Tactical UAV as a Combat Identification Tool

5. FUNDING NUMBERS

6. AUTHOR(S)
Farmer, Michael P.

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Naval Postgraduate School
Monterey, CA 93943-5000

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)
N/A

10. SPONSORING / MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government.

12a. DISTRIBUTION / AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT *(maximum 200 words)*

Soldiers maneuvering on the 21st Century battlefield are issued state-of-the-art equipment. Despite this, the tools at their disposal to identify targets as being a "friend" or a "foe" have changed little since Operation Desert Storm. While improved optics on late model combat systems are extending gunners' abilities to identify targets at extended ranges, an optics-vs.-ballistics gap remains in the majority of U.S. Army ground maneuver forces. This gap, and other battlefield factors, increases the likelihood of fratricides in combat.

This thesis examines the feasibility of using the Army's Tactical Unmanned Aerial Vehicle (TUAV) as a combat identification (CID) tool for troops at the tactical level. Three scenarios were modeled and multiple simulations run to identify potential problems in using the TUAV as a CID tool, as well as ways to improve the system if it is used in this role. Model considerations included current and planned future datalink bandwidths, system delays, normal vs. immediate taskings, and travel times to mission areas.

The thesis demonstrates that if TUAVs are properly integrated into tactical mission planning and imagery analysts possess the necessary level of vehicle identification training (to include thermal identification training), the TUAV can function well as a CID tool.

14. SUBJECT TERMS
UAV, Combat Identification, Reconnaissance.

15. NUMBER OF PAGES 131

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	**18. SECURITY CLASSIFICATION OF THIS PAGE**	**19. SECURITY CLASSIFICATION OF ABSTRACT**	**20. LIMITATION OF ABSTRACT**
Unclassified	Unclassified	Unclassified	UL

NSN 7540-01-280-5500 **Standard Form 298 (Rev. 2-89)**
Prescribed by ANSI Std. 239-18

THIS PAGE INTENTIONALLY LEFT BLANK

Approved for public release; distribution is unlimited

FEASIBILITY OF THE TACTICAL UAV AS A COMBAT IDENTIFICATION TOOL

Michael P. Farmer
Major, United States Army
B.S., University of North Alabama, 1990

Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN INFORMATION TECHNOLOGY MANAGEMENT

from the

NAVAL POSTGRADUATE SCHOOL
September, 2001

Author: ______________________
Michael P. Farmer

Approved by: ______________________
John Osmundson, Thesis Advisor

____
William Welch, Associate Advisor

____
Dan Boger, Chairman
Information Systems Academic Group

THIS PAGE INTENTIONALLY LEFT BLANK

ABSTRACT

Soldiers maneuvering on the 21st Century battlefield are issued state-of-the-art equipment. Despite this, the tools at their disposal to identify targets as being a “friend” or a “foe” have changed little since Operation Desert Storm. While improved optics on late model combat systems are extending gunners’ abilities to identify targets at extended ranges, an optics-vs.-ballistics gap remains in the majority of U.S. Army ground maneuver forces. This gap, and other battlefield factors, increases the likelihood of fratricides in combat.

This thesis examines the feasibility of using the Army’s Tactical Unmanned Aerial Vehicle (TUAV) as a combat identification (CID) tool for troops at the tactical level. Three scenarios were modeled and multiple simulations run to identify potential problems in using the TUAV as a CID tool, as well as ways to improve the system if it is used in this role. Model considerations included current and planned future datalink bandwidths, system delays, normal vs. immediate taskings, and travel times to mission areas.

The thesis demonstrates that if TUAVs are properly integrated into tactical mission planning and imagery analysts possess the necessary level of vehicle identification training (to include thermal identification training), the TUAV can function well as a CID tool.

THIS PAGE INTENTIONALLY LEFT BLANK

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF ACRONYMS

A2C2	Army Airspace Command and Control
ABCCC	Airborne Battlefield Command and Control Center
ADT	Airborne Data Terminal
AFATDS	Advanced Field Artillery Tactical Data System
AGL	above ground level
ASAS	All Source Analyses System
ASCIET	All Service Combat Identification Evaluation Team
ATC	air traffic control
ATR	automatic target recognition
AV	Air Vehicle
AVO	air vehicle operator
AWACS	Airborne Warning and Control System
BCIS	Battlefield Combat Identification System
BDE	Brigade
C2	command and control
CAS	close air support
CDL	Common Data Link
CDR	commander
CGS	Common Ground Station
CID	combat identification
CIDDS	Combat Identification for the Dismounted Soldier
CIP	Combat Identification Panel
COA	course of action
COC	combat operations center
CSS	combat service support
DARPA	Defense Advanced Research Project Agency
EO	electro-optic
FAAD	forward area air defense
FLIR	forward looking infrared radar
FSCOORD	Fire Support Coordinator
GALE	Generic Area Limitation Environment
GCS	Ground Control Station
GDT	Ground Data Terminal
GRCS	Guardrail Common Sensor
HVT	high value target
IFF	Interrogate Friend or Foe
IOT&E	Initial Operation Test and Evaluation
IR	infrared
JCIET	Joint Combat Identification Evaluation Team
JSTARS	Joint Surveillance Target Attack Radar System
L/R	launch and recovery

MAGTF	Marine Air Ground Task Force
MMP	Modular Mission Payload
MMW	millimeter wave
MPO	mission payload operator
MSE	mobile subscriber equipment
MSL	mean sea level
MTI	moving target indicator
NAI	named area of interest
NSA	National Security Agency
NVESD	Night Vision and Electronics Sensors Directorate
OPTEMPO	operational tempo
PM CI	Program Manager Combat Identification
PM FLIR	Product Manger Forward Looking Infrared Radar
R&S	reconnaissance and surveillance
ROC-V	Recognition of Combat Vehicles
ROE	rules of engagement
RSTA	reconnaissance, surveillance, and target acquisition
RVT	Remote Video Terminal
RWS	Remote Work Station
SA	situational awareness
SAR	synthetic aperture radar
SIGINT	signals intelligence
SINCGARS	Single Channel Ground and Airborne Radio System
TACLAN	tactical local area network
TCDL	Tactical Common Data Link
TF	Task Force
TOC	tactical operations center
TTP	tactics, techniques, and procedures
TUAV	Tactical Unmanned Aerial Vehicle
USJFC	United States Joint Forces Command

ACKNOWLEDGMENT

The author would like to thank those people and organizations who contributed to the investigation and writing of this thesis. Special thanks to Dr. John Osmundson for his time and patience throughout the entire process and to CDR (Ret) Joseph Welch for his invaluable advise and assistance. Finally, thanks to the Joint Combat Identification Evaluation Team (JCIET) staff at Eglin Air Force Base, Florida for sharing their experience and insights on the use of unmanned aerial vehicles in the combat identification process.

THIS PAGE INTENTIONALLY LEFT BLANK

I. INTRODUCTION

Iraq, February 27, 1991: In the hours of darkness preceding dawn, portions of two U.S. Army units made contact during the early stages of Desert Storm's ground war. The result – one soldier dead and another wounded, both due to fratricide or "friendly fire". The unit which fired, the 3rd Armored Cavalry Regiment, is known to be one of the finest ground combat forces in the world…well-trained, well-led, and always equipped with the most modern equipment available in Army inventories. Yet on the morning of 27 February, this well-trained, well-led, well-equipped force positively identified Iraqi forces to their front - that were in actuality another U.S. force – and engaged them [Ref. 1]. Now, as in 1991, the vast majority of Army forces lack the tools necessary for tactical troops to make combat identification (CID) decisions – that is, the ability to look at a detected target and positively identify it as friendly or hostile.

A. PURPOSE

The purpose of this thesis is to examine whether the Army's Shadow 200 Tactical Unmanned Aerial Vehicle (TUAV), the first variant in new series of UAVs the Army is fielding, is a viable tool to aid the tactical (Brigade and below) commander in performing CID on today's battlefield.

B. RESEARCH QUESTIONS

The overall value of the Shadow 200 system in providing combat identification to Brigade-level commanders can be decomposed into the following research questions:

(1) Does the Shadow 200's thermal resolution permit operator detection and resolution from threshold survivable stand off range?

(2) How many CID-supporting missions can a Shadow 200 perform during a full operational window of four hours? How many in an immediate tasking mission?

(3) What factors need to be considered in order to properly model the TUAV system as a CID tool?

(4) What are the results of modeling TUAV operational timelines in the CID process when cued by J-STARS?

(5) How large a role does imagery analyst vehicle identification training play in determining the success of using TUAV's as a CID tool?

(6) What impact does the TUAV operator "man in the loop" have on the CID process? Are there ways to reduce this impact?

C. EXPECTED BENEFITS OF THIS THESIS

The conclusions and recommendations of this thesis are expected to aid tactical commanders in deciding whether the TUAV is appropriate for use in their CID processes and if so, some ways to improve the TUAV systems ability to function as a CID tool.

II. BACKGROUND

A. FRATRICIDE

Fratricide is defined as the employment of friendly weapons and munitions with the intent to kill the enemy or destroy his equipment or facilities, which results in unforeseen and unintentional death or injury to friendly personnel [Ref. 2]. During the Gulf War in 1991, 24 percent of Americans killed in action –35 of 146 – died at the hands of other U.S. forces. Similarly, 15 percent of those wounded – 72 of 467 – were victims of "friendly fire" [Ref. 3]. This results in an overall fratricide rate of 17 percent. Of these fratricides, 61 percent resulted during ground-to-ground engagements [Ref. 4].

Why does fratricide occur most frequently on the ground? One reason is that the battlefield is "dirtier" than the other combat arenas, such as the air – no Interrogate Friend or Foe (IFF) such as our military aircraft have to differentiate friendly elements from enemy, no radar or acoustic profiles, sporadic communications much of the time, a much larger number of entities to keep track of, etc. Add to this that our mechanized forces' ballistic capabilities far exceed their associated optical capabilities – i.e., we can shoot farther than we can see – and it becomes clear why ground fratricide numbers are higher. This is particularly true in mechanized units, where targeting and weapons systems continue to improve in lethality and range.

Some of the newer systems being fielded will reduce the number of fratricides, such as the Second Generation Forward Looking Infrared (2nd Gen FLIR) sight used by the M1A2-SEP main battle tank and the M2A3/M3A3 Bradleys. The 2nd Gen FLIR is a fully integrated engagement-sighting system designed to provide the gunner and tank commander with significantly improved day and night target acquisition and engagement capability. The system allows 70 percent better acquisition, 45 percent quicker firing and greater accuracy, and a gain of 30 percent in range for target acquisition and identification [Ref. 5]. Unfortunately fielding of the M1A2-SEPs is only just beginning, so at present most of the Army's heavy tanks still rely on the older thermal imaging systems. Additionally, current planning for the Army Transformation "Legacy Force" calls for half of the tanks to be digitized M1A1s – just over 1,500 of these remodeled M1A1s total. That means the troops manning these systems will for the most part be dealing with the M1A1s older technology, but will be able to communicate with the digital systems of more modern combat platforms. The Army's intent is to upgrade these M1A1-Digital (M1A1D) tanks with 2nd Generation FLIR, but as of now the funding is not there. Finally, the pre-positioned stocks of tanks and fighting vehicles, such as those on station in Kuwait and Qatar for Middle East contingency operations, all utilize earlier generation optics – the same optics used during Desert Storm in 1991.

B. COMBAT IDENTIFICATION (CID)

1. CID Defined

The Joint Combat Identification Evaluation Team (JCIET), a joint command under United States Joint Forces Command (USJFCOM) aimed at fostering improved joint tactics, techniques, and procedures (TTPs) across all CID mission areas, defines CID as "a process that results in a shooter determining a target's identification in support of an engagement decision under specified Rules of Engagement (ROE)" [Ref. 6]. Accurate combat engagement is not only a question of identifying what type of equipment we are looking at, but also being able to ascertain whether the target is friendly, enemy, or neutral in order to make an engagement decision.

2. Current CID Efforts

Various systems and efforts are underway to deal with ground-to-ground CID issues. The Army's proponent for CID is Program Manager Combat Identification (PM CI). PM CI is actively pursuing CID answers through the following programs.

a. Battlefield Combat Identification System (BCIS)

BCIS uses directional, millimeter wave technology to provide positive identification of BCIS-equipped equipment on the battlefield. It is a "pointing" fratricide-prevention system. The potential shooter aims his weapon at the target and "queries" it. The interrogation will let him know that the target is friendly so long as the "target" is also mounting a BCIS system. The drawback is obvious. Vehicles lacking BCIS or with an inoperative BCIS system could be friendly or neutral. The BCIS "shooter" does not have a clear picture of what he is facing. The risk is that one of two things can happen: first, he might shoot a non-hostile player; second, erring to the side of caution and not engaging, the friendly "shooter" is engaged by what turned out to be an enemy system.

b. Combat Identification for the Dismounted Soldier (CIDDS)

CIDDS is a secure laser interrogation and radio frequency response system that will be used by dismounted infantry to positively identify dismounted friendly troops. Like BCIS, it will only identify other friendlies using operational CIDDS equipment.

c. Quick Fix Devices

Quick Fix Devices are designed to give the shooter a visual indication of friendly platforms or dismounts. They fall into three varieties: near-infrared Budd and Phoenix Lights and thermal Combat Identification Panels (CIPs). Like the name states, these systems were designed as a "quick fixes" after Desert Storm to prevent friendly casualties until more permanent systems such as BCIS and CIDDS came on line.

d. Improving Situational Awareness (SA)

Improving SA means increasing shooters' awareness of what is happening on the battlefield around them. This can be accomplished through SA systems that provide crewmembers additional information about known friendly and enemy positions on the battlefield or simply by making sure that all personnel have updated graphics and are kept informed of the friendly and enemy situations through radio transmissions.

3. Thesis CID Focus

Combat identification is critical for all mission areas - Ground to Ground, Ground to Air, Air to Ground, and Air to Air. This paper, however, will look at the process only from the Ground-to-Ground perspective, as this is where the TUAVs viability in CID comes into play.

C. THE TACTICAL UNMANNED AERIAL VEHICLE (TUAV)

The TUAV program acquires a system of complementary Tactical UAVs that provide operational and tactical commanders near-real time, highly accurate, sustainable capabilities for over the horizon/hill reconnaissance, surveillance, target acquisition, and battle damage assessment. The program will support Army Corps/Division/Brigades, USMC MEFs and Navy Amphibious Assault Groups. The first in this new generation of TUAVs will be the Shadow 200, designed specifically for the tactical commander. The Initial Operation Test & Evaluation (IOT&E) program began in May 2001.

The Shadow 200 is designed to be the Brigade Commander’s UAV, allowing him to gain dominant situational awareness of his battlespace. It will be a key component of the Brigade’s collection package, giving commanders the ability to “see” into areas that ground reconnaissance elements cannot penetrate or move to in a timely manner and can also provide “eyes” on heavily protected areas where commanders do not wish to send manned aerial platforms. The TUAV can be linked to and cued by wide area sensors such as the Joint Surveillance Target Attack Radar System (JSTARS), Guardrail Common Sensor (GRCS), Artillery Counter Mortar/Battery Radars and Forward Area Air Defense Command and Control (FAAD C2).

1. Shadow 200 System Overview

The Shadow 200 TUAV system consists of five basic components: the Ground Control Stations (GCS) and related equipment, the Air Vehicles (AV), the Modular Mission Payloads (MMP), the Remote Video Terminals (RVT), and communications. A TUAV system will include four AVs, three for mission execution plus one spare, and will be able to provide 12 hours of coverage within a 24-hour period. For no more than three consecutive days the system can provide 18 hours of coverage per 24-hour period. Full manning of a system requires a crew of 22 personnel for operation and maintenance at the described operational tempo (OPTEMPO).

The system is designed for ease of use, operation, recovery, and maintenance. It presents a small profile in order to reduce its footprint on the battlefield, aid in rapid deployability/set-up/teardown, and to reduce impact on the Brigade's combat service support (CSS) resources.

2. System Components

a. Ground Control Stations (GCS)

The GCS and its related equipment perform two primary functions. First, it is the primary means of operating, controlling, and tracking the AV. The GCS's second primary function is to manipulate the payload and receive/process telemetry and video downlinks. Additionally, it incorporates mission-planning functions that allow call for and adjustment of indirect fires.

There are two GCSs per TUAV system, each in a HMMWV mounted command and control (C2) shelter (Figs. 1 and 2). The GCS has two operators - an Air Vehicle Operator (AVO) and a Mission Payload Operator (MPO).

Each GCS can only communicate with and control one AV at a time. A normal mission would see a GCS at the Launch and Recovery (L/R) site handle getting the birds airborne. Once in the air, it will pass off the AV to the other GCS for mission execution while it prepares another Shadow for launch. Once the mission is complete, the GCSs could again switch AVs, with the L/R site handing off a fresh AV to its sister GCS and taking control of the original platform for landing and recovery.

Figure 1.Ground Control Station (GCS) – Exterior View [From: Ref. 7]

Figure 2. Ground Control Station (GCS) – Interior View [From: Ref. 7]

b. Air Vehicles (AV)

The Shadow 200 is a mid-wing monoplane with a twin boom empennage supporting an inverted-V tail (Fig. 3). Constructed of composite materials and powered by a rotary engine, the AV has an endurance of four hours on station at 50 kilometers from the L/R site [Ref. 8]. A clear line of site is required between the AV and the Ground Data Terminal located at the controlling GCS site.

Figure 3. Shadow 200 AV [From: Ref. 7]

Due to its small size and composite materials, the AV is not visually detectable from ranges exceeding 4,000 feet and is not audible from ranges exceeding 2,000 feet. It can operate in less than ideal weather conditions flying at altitudes of 14,000 feet Mean Sea Level (MSL) or greater, while its nominal operating altitudes/survivable altitudes are from 8,000 to 10,000 feet Above Ground Level (AGL) for day operations and 6,000 to 8,000 feet AGL for night operations (Fig. 4).

Characteristics	TUAV
Altitude: Maximum (km,ft) Operating (km,ft)	4.6km 14,000ft 1.8 – 3.7km 6,000 – 12,000 ft
Endurance (Max): (hrs)	5 hrs*
Radius of Action: (km,nm)	50 km* 31 nm*
Speed: Maximum (km/hr,kts) Cruise (km/hr,kts) Loiter (km/hr,kts)	200 km/hr 105 kts 120 – 130 km/hr 65 – 70 kts 120 – 130 km/hr 65 – 70 kts
Climb Rate (Max): (m/min,fpm)	366 m/min 1200 fpm
Propulsion: Engine Propeller	One rotary One pusher
Avionics: Transponder Navigation	Mode IIIC, IV (IFF) GPS
Launch & Recovery Launch Recovery	 Rail Launched (soccer field size) Arrested Recovery (soccer field size)
Guidance & Control	Remote Control/Preprogrammed/Autonomous
Fuselage: Length (m/ft) Width (m/ft)	3.4 m 11 ft 4.0 m 13 ft
Wingspan: (m/ft)	3.9 m 12.8 ft
Weight: Max (kg/lbs) Payload (kg/lbs)	147.6 kg 328 lbs 27.3 kg 60 lbs
Fuel: Type Capacity (kg/lbs)	MOGAS 23.1 kg 50.7 lbs

*TUAV has demonstrated capability to exceed requirements

Figure 4. Shadow 200 Specifications [From: Ref. 8]

c. *Modular Mission Payloads (MMP)*

The Shadow 200 payloads incorporate a modular design. The baseline sensor is the Electro-Optic / Infrared (EO/IR) payload (Fig.5). The secondary priority payload is a Synthetic Aperture Radar / Moving Target Indicator (SAR/MTI) payload, then a Communications / Data Relay payload [Ref. 7].

Figure 5. EO/IR Payload [From: Ref. 7]

The EO/IR payload is a multi-mode, Forward Looking Infrared / Television (FLIR/TV) sensor. The threshold (minimum) requirement of the system is to recognize an APC-sized target at operational altitudes of 8,000 feet AGL (day) and 6,000 feet AGB (night). Performance testing was conducted in both EO and IR modes of operation . The MMP performance in both modes exceeded requirements.

In IR mode, which has three selectable fields of view, the requirement was for a 70 percent probability of detection of a 3.5 square meter (m^2) target at 3.5 km slant range. The 70 percent probability was reached at 4.75 km (Figure 6). The probability of detection at the targeted range of 3.5 km was just below 90 percent.

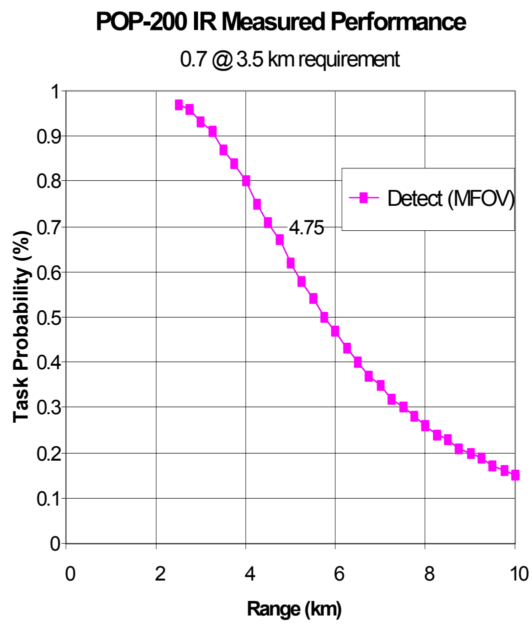

Figure 6. Measured IR Performance [From: Ref. 9]

In EO mode, the requirement was for 80 percent probability detection at 3.8 km. There was actually a 90 percent probability of recognition at the 3.8 km mark and an 80 percent probability of detection at 4.4 km (Fig. 7).

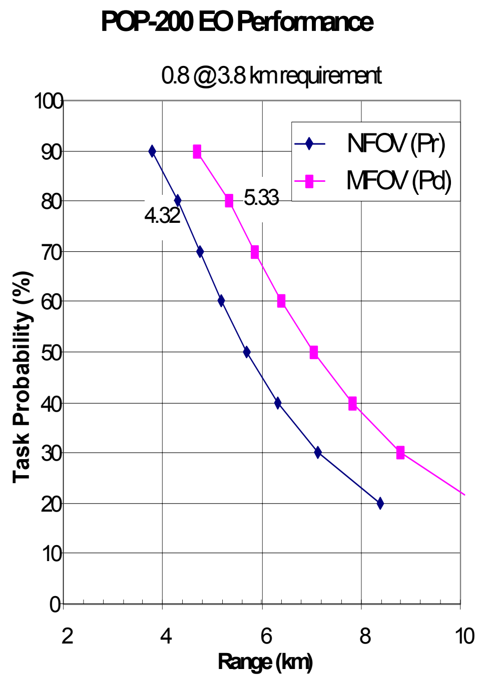

Figure 7. EO Measured Performance [From: Ref. 9]

There is no automated target recognition system within the AV payload or at the GCS. This is true not only of the Shadow 200 system, but of all UAVs. All target recognition (what the target is) and identification (friend/foe/neutral) occurs at the operator level – someone looking at the live imagery downlinked to the GCS or a Remote Video Terminal (RVT). Training will be discussed in a in a later chapter dealing with conclusions and recommendations, but it is critical in the process. A soldier or Marine well-trained in target identification does not need the AV to fly as close to the target, or remain on station as long, in order to make a target identification. This is particularly true at night. While the IR sensor often is able to pick up potential targets more readily through obscuration, foliage, etc., it is useful in the identification process to switch between normal and thermal imagery. During hours of darkness this is not an option, and the operators making identification decisions must be trained not only to know the physical characteristics of various vehicles, but also the thermal characteristics of the same vehicles. This is a much more difficult standard upon which to make a CID decision (Figure 8).

Figure 8. IR Imagery from EO/IR Payload [From: Ref. 7]

d. Remote Video Terminals (RVT)

Each Brigade's TUAV system includes four RVTs, dispersed throughout the Brigade's area of operations according to the commander's wishes in order to best support his scheme of maneuver. The RVT (Fig. 9) is a portable, rugged system that receives, processes, and displays near real time (NRT) video images and telemetry from the AV. The terminals receive video and telemetry signals from the AV through either the antenna or the GCS. When within 50 kilometers of the AV, an RVT can receive direct downlink from the Shadow 200 and display annotated imagery to the operator, store imagery, recall selected segments, and display near real time imagery with annotation to include date/time group, north seeking arrow, AV position and heading, and selectable target location when in the center field of view (in latitude/longitude, Military Grid Reference System, and Universal Transverse Mercator coordinates).

Figure 9. Remote Video Terminal (RVT) [From: Ref. 7]

e. Ground Communications

The Ground Control Station provides a ready interface to the existing secure command, control, communications, computers, and intelligence (C4I) architecture. This includes the JSTARS Common Ground Station (CGS), the Advanced Field Artillery Tactical Data System (AFATDS), the All Source Analyses System (ASAS), and Army Airspace Command and Control (A2C2).

Intelligence reports from the GCS include secure voice, electronic dissemination, and/or video via the various communications systems in the GCS. Secure communications and intelligence dissemination are provided through the DoD tactical radios (VHF and UHF), Mobile Subscriber Equipment (MSE), and the Tactical Local Area Network (TACLAN).

Ground components use Service standard tactical communications equipment and procedures. TUAV communications must interface with selected standard DoD C4I systems, architectures, and protocols. All communications must be interoperable with National Security Agency (NSA) approved encryption systems. The system will have UHF communications capable of secure operations with Air Traffic Control (ATC) agencies and also with Airborne Warning and Control System (AWACS) and Airborne Battlefield Command and Control Center (ABCCC) aircraft. It will be capable of relaying UHF communications through the AV.

The tactical communications system will provide integrated communications to the TUAV tactical users for mission support and communication between shelters. Communications between shelter operators, external system users, and support units will be via Single Channel Ground and Airborne Radio System (SINCGARS) radios. Telephones will be used for comms between the TUAV Control Shelters, Mobile Maintenance Facility, and system users. A tactical telephone capable of digital data and voice communications will be part of the TUAV system. Digital data will be translated to standard formats for use by shelter consoles. Two telephone networks will be in operation: MSE for telephone (voice/data) communication and one fiber optic net (Ethernet) for intra-shelter voice/data communication. Figure 10 depicts the GCS radio equipment and communication devices.

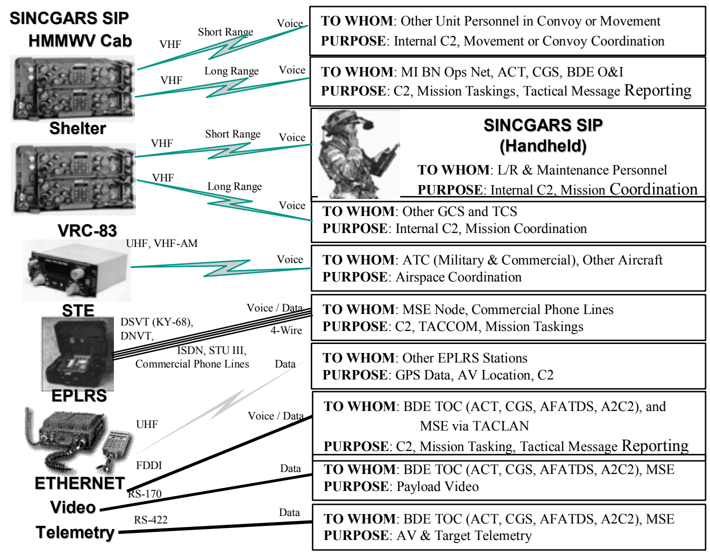

Figure 10. GCS Radios and Communications Devices [From: Ref. 8]

3. Tactical Common Data Link (TCDL)

The TCDL program's purpose is to develop a family of interoperable digital, secure, data links supporting both unmanned and manned airborne reconnaissance platforms [Ref. 10]. As applied to the Brigade's TUAV system, it is the data link between the GCS and the AV. The TCDL will provide near real time connectivity and interoperability between multiple TCDL collection platforms (the TUAVs), TCDL surface terminals (the GCSs as well as the receive-only RVTs), and currently fielded Common Data Link (CDL) interoperable systems operated throughout the military and other government agencies.

The TCDL provides a full-duplex, digital transmission between AV payloads and surface terminals through LOS transmissions. The command link (the uplink between the GCS and the TUAV) will be at the current CDL data rate of 200 Kbps. The video downlink from the TUAV to the GCSs or RVTs is currently at 10.71 Mbps, with a planned improvement in the near future to 45 Mbps. The uplink frequency operating range is in the 15.15 to 15.35 GHz band, and the downlink range is the 14.4 to 14.83 GHz band. The contractor requirement is for TCDL to be tunable in 5 MHz step sizes or less. The LOS slant range planning distance is 200 km at 15,000 feet AGL.

The primary components of the TCDL are the Ground Data Terminal (GDT) and the Airborne Data Terminal (ADT).

a. Ground Data Terminal (GDT)

Located at the GCS, the GDT transmits command and control guidance to the AV and receives MPEG-2 video imagery transmitted from the AV (Fig. 11).

b. Airborne Data Terminal (ADT)

The ADT is located in the AV itself. It receives guidance instructions from the GDT located at the GCS and transmits imagery back to the GDT (Fig. 12).

Figure 11. TCDL Ground Data Terminal (GDT) [From: Ref. 11]

Figure 12. TCDL Airborne Data Terminal (ADT) [From: Ref. 11]

III. MODELING AND SIMULATION

A. MODEL DEVELOPMENT

This chapter examines the feasibility of using the TUAV as a CID tool through the use of modeling and simulation. Three scenarios will be modeled and their processes examined to develop an understanding of the potential problems in using the TUAV system as a CID tool and improvements that can be made to enhance the system if it is used in this role.

1. Terminology

a. Modeling

A model is a logical description of how a system, process, or component behaves [Ref. 12]. Instead of interacting with a real system, we can create a model corresponding to certain aspects of the system.

b. Simulation

Simulation involves designing a model of a system and carrying out experiments on the model. The purpose of these experiments is to determine how the real system (being modeled) performs and to predict the effect of changes to the system as time progresses.

2. Extend Modeling Software

Extend software was used for the modeling and simulation. Extend is a dynamic, iconic simulation environment with a built-in development system for extensibility. It enables the user to simulate discrete event, continuous, and combined discrete event/continuous processes and systems. Additionally, Extend allows users to build their own modules.

Most systems can be modeled using Extend's pre-built blocks, therefore no programming is necessary. The blocks are grouped into libraries according to function. The user places desired blocks in his model by selecting them from a drag-and-drop menu on the toolbar. Once selected, the blocks appear in the Extend desktop workspace. Block connections are made using a standard mouse. Block parameters are set through its dialogue box. Data can be entered directly into block dialogues, interactively using controls, or read in from files as the simulation runs.

3. Modeling Considerations

a. Description of the Process Being Modeled

The model will simulate a process that begins with a wide area sensor's (JSTARS) reception of moving target indicators (MTIs) and tracks the progress of the MTIs through the Brigade's decision on a course of action (COA). The following steps take place in the simulation:

- Data flows from the JSTARS platform to the JSTARS Common Ground Station (CGS) located at a Brigade Tactical Operations Center (TOC).

- A decision-maker at the TOC (egs. Brigade Commander, Executive Officer, Operations Officer) decides how the Brigade will further develop the MTI item…i.e., what internal asset they will use to gain more intelligence on the MTI, or what outside agency they will request to further develop the item for them.

- The item is routed to the selected node for further development (if tasked to the TUAV, the item continues in the simulation; if not, the MTI exits the simulation).

- The TUAV GCS has an AV prepared (if necessary) and sends mission commands to the AV on the TCDL.

- The AV moves to the mission area and begins transmitting imagery to the GCS and the RVTs.

- Decision-makers at the TOC decide on a COA after reviewing the imagery…i.e., shoot or don't shoot.

- The MTI item exits the simulation.

Other factors considered in order to make the model as realistic as possible are bandwidth limitations, preparation and travel time to get an AV into the mission area, the slant range of the AV when it detects the target, and the Brigade decision time to decide a COA.

A final note on the simulation. Many of the model's attributes - video size, for example - are set early (before they would actually occur in the real world) in order to simplify the model. This is possible because Extend allows users to set attribute values at any point. It is often more economical to set attribute values for items as they are generated at the beginning of the simulation and then pull and measure the values at a later point in the simulation (when they would be occurring in the real world).

b. Goal of Simulation

To use the simulation as a process model for the utilization of the Shadow 200 TUAV system as a CID tool and identify areas where the system can be improved if it is to serve in this role.

c. Design Basis

Keeping in mind that the question involved in this thesis is the feasibility of using the TUAV for CID purposes, the first step was to decide the type of model to build…discrete event, continuous, or a combination of the two. For the systems simulated, the data and information flow are event-driven. Based on this, discrete event models are used throughout.

d. Design Steps

The following process was used in designing the models: identify the nodes involved (JSTARS, Brigade TOC, TUAV system); examine the architecture of the nodes involved; replicate the overall system nodes and architecture using Extend modeling blocks and connections; set realistic parameters for the nodes; run the simulation; analyze the simulation results, focusing on whether an identification could be made by a trained operator (the AV is inside detection range and not within threshold survivable stand off range) and the delays occurring for preparation, uplink, travel, and downlink; make adjustments to parameters to answer further questions; analyze new results; repeat adjustments to the model as needed; draw conclusions based on the results.

B. SIMULATION PHASES

Figure 13 represents the entire model from MTI reception by a wide area sensor through the CID decision. Following are the phases of the simulation and the actions occurring in each.

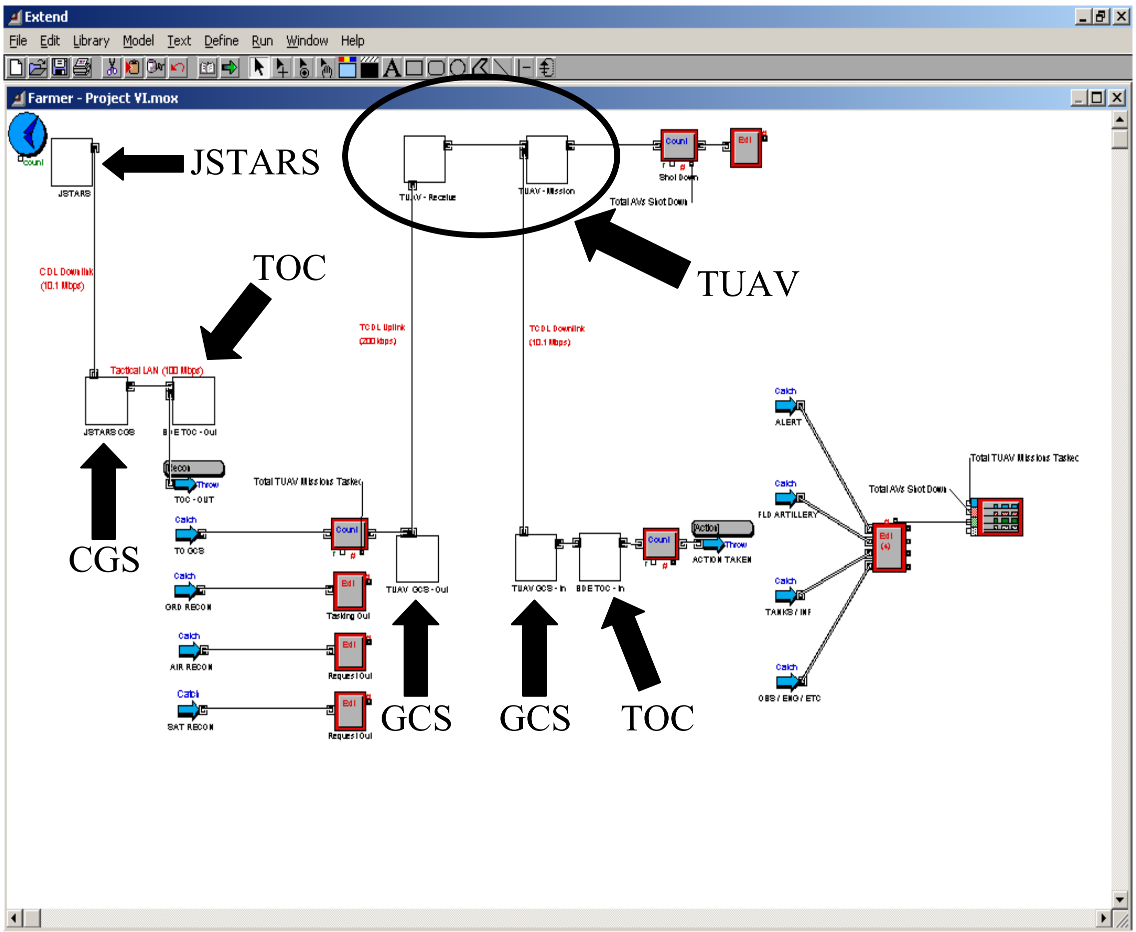

Figure 13. MTI Reception through CID Decision

1. JSTARS

Figure 14 illustrates what is occurring within the “JSTARS” hierarchical block. In the JSTARS block, MTI items are being produced at specified intervals by an Extend Generator block. After generation, several attributes are associated with the items as they are created:

a. MTI MSG

An Input Random Number block sets the MTI message size in megabits (Mb). The output will be a real number between two selected values.

b. CGS MSG

Another Input Random Number block, this one setting the size of the message traveling from the JSTARS CGS to the Brigade TOC (in Mb). The output will be a real number between two selected values.

c. GCS OUT

An Input Random Number block setting the size of the message being transmitted to the AV in Mb. The output will be a real number between two selected values.

d. VID SIZE

An Input Random Number block setting the size of the MPEG-2 video imagery (in Mb) being transmitted from the AV to the GCS. The output will be a real number between two selected values.

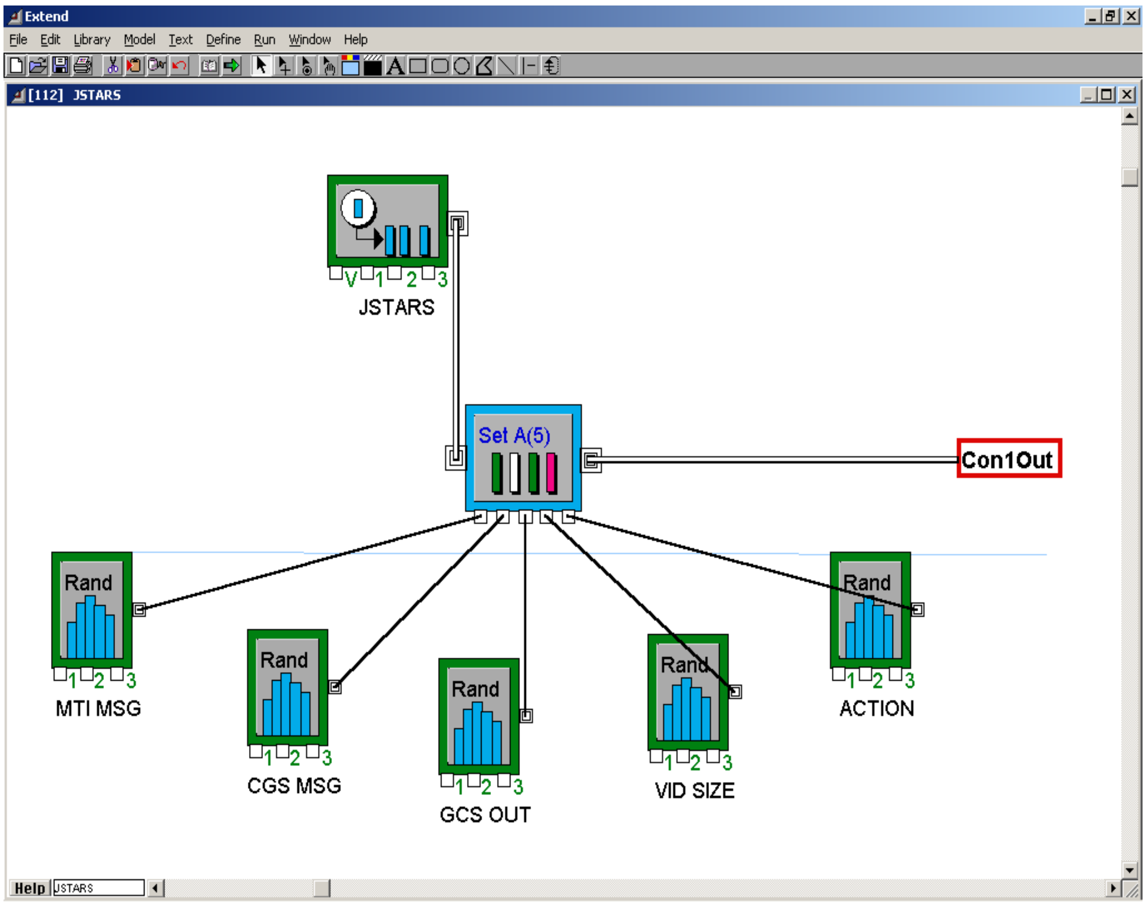

Figure 14. JSTARS Hierarchical Block

e. ACTION

An Input Random Number block used to select which node (type of firing unit) is actioned as a result of the Brigade's decision upon review of the TUAV video imagery. For this block, an empirical table is used to make the selection. Each of the nodes is assigned a position in the empirical table and a percentage selection value.

Once the final attribute is set, the item moves from the "JSTARS" block to the "JSTARS CGS" block (Fig. 15).

2. JSTARS CGS

At the CGS block, the item's MTI Message size (MTI MSG) attribute is read. This is the size of the message passing from the JSTARS aircraft to the CGS. The message is then delayed by an amount equal to the message size divided by the bandwidth (in this case 10.1 Mbps, the data rate of the Common Data Link, or CDL). Once the delay is complete, the item passes to the "Brigade TOC – Out" block (Fig. 16).

3. Brigade TOC – Out

The CGS MSG attribute is read and a delay occurs equal to the message size divided by the bandwidth as the item arrives at the "TOC – Rec" node. In this case the message is passing over fast Ethernet, therefore the data rate is 100 Mb per second (Mbps). The item then passes to the Brigade TOC-Send node. Here it experiences a delay of one to five minutes to account for the time it takes the Brigade to decide who will be tasked to further develop the MTI (TUAV or a ground reconnaissance element from within the Brigade) or what agency a request will go to for further development (requests for aircraft reconnaissance or satellite imagery).

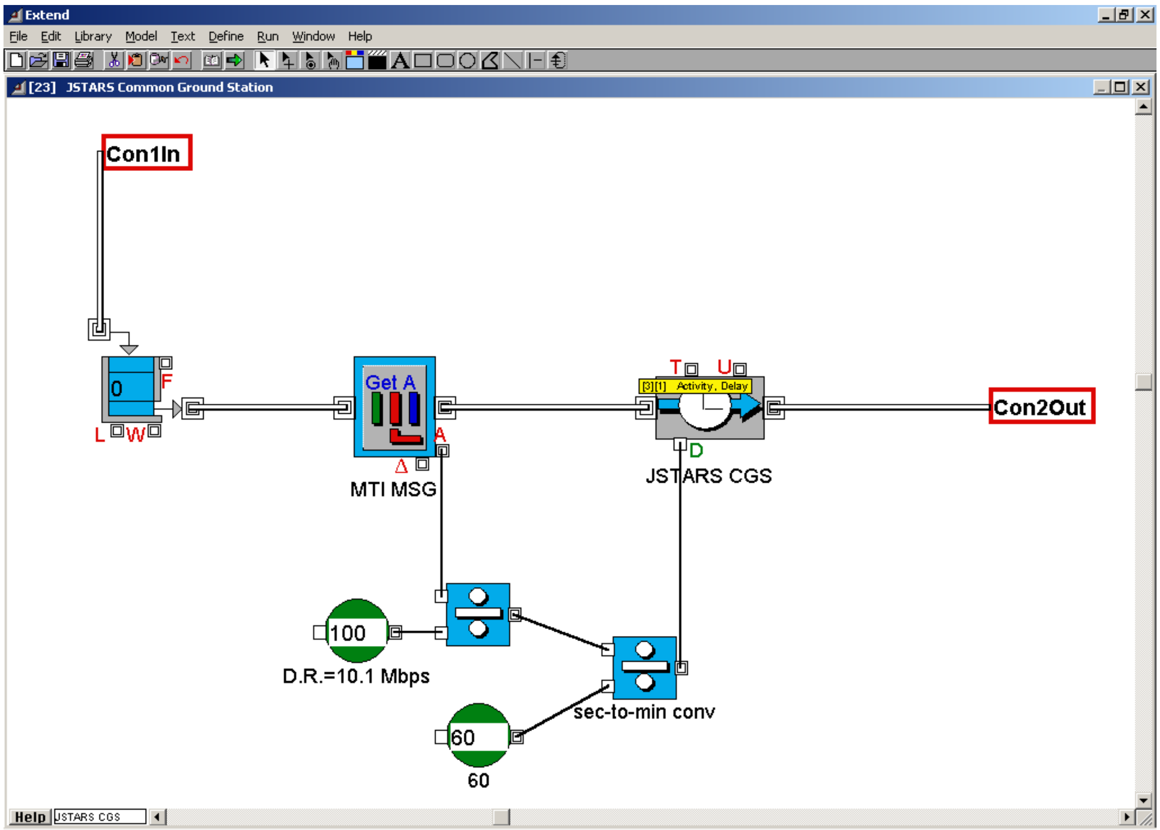

Figure 15. JSTARS CGS Hierarchical Block

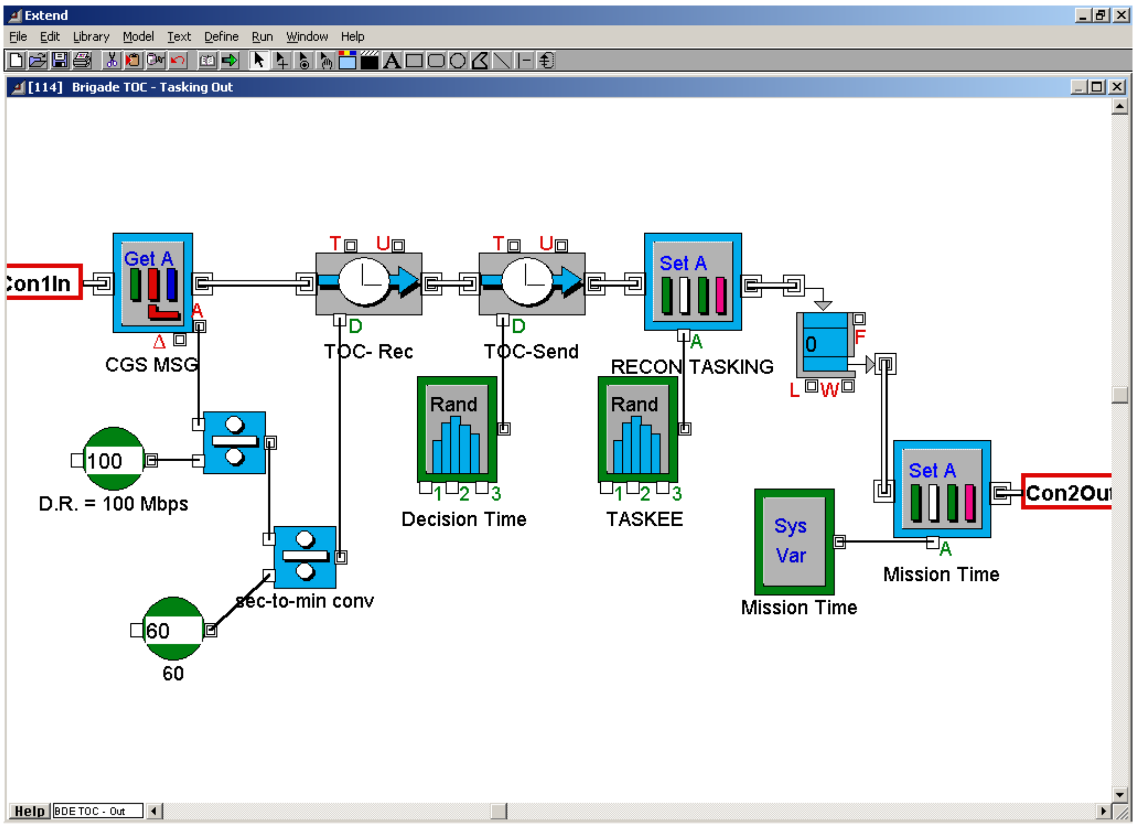

Figure 16. BRIGADE TOC – OUT Hierarchical Block

On exiting the TOC-Send block, the item's TASKEE attribute value is set randomly through an empirical table. This attribute determines which node receives the tasking/request to develop the MTI located by JSTARS. The possible values of this attribute are GCS (for TUAV tasking), GRD RECON (if being tasked to reconnaissance elements within the Brigade), AIR RECON (Air Force), and SAT RECON. Each of these table values has a percentage associated with it.

Once the TASKEE value is set, the item moves through a FIFO (First In, First Out) Queue and is prepared to move to the selected node for further development. Before moving to the selected TASKEE node, an attribute is assigned to the item that marks the time that the TASKEE was assigned the mission. The item then passes on to an Extend Throw block, "TOC-Out". This block reads the TASKEE attribute value and directs the item to the proper node (Fig. 17). If the receiving node is anything other than the GCS, the item exits the system. If the receiving node is the GCS node, the MTI item continues in the simulation and moves to the TUAV GCS for processing.

4. TUAV GCS – Out

Once into the "TUAV GCS - OUT" hierarchical block (Fig. 18), the item experiences a delay to account for the time either to prepare a fresh AV for the mission or to redirect an airborne AV with an immediate tasking. Once the delay is complete, the delay between mission assignment and the time the GCS was ready to begin the mission is measured. This is the "Delay – Prep". The item then proceeds to a FIFO Queue and is prepared to continue.

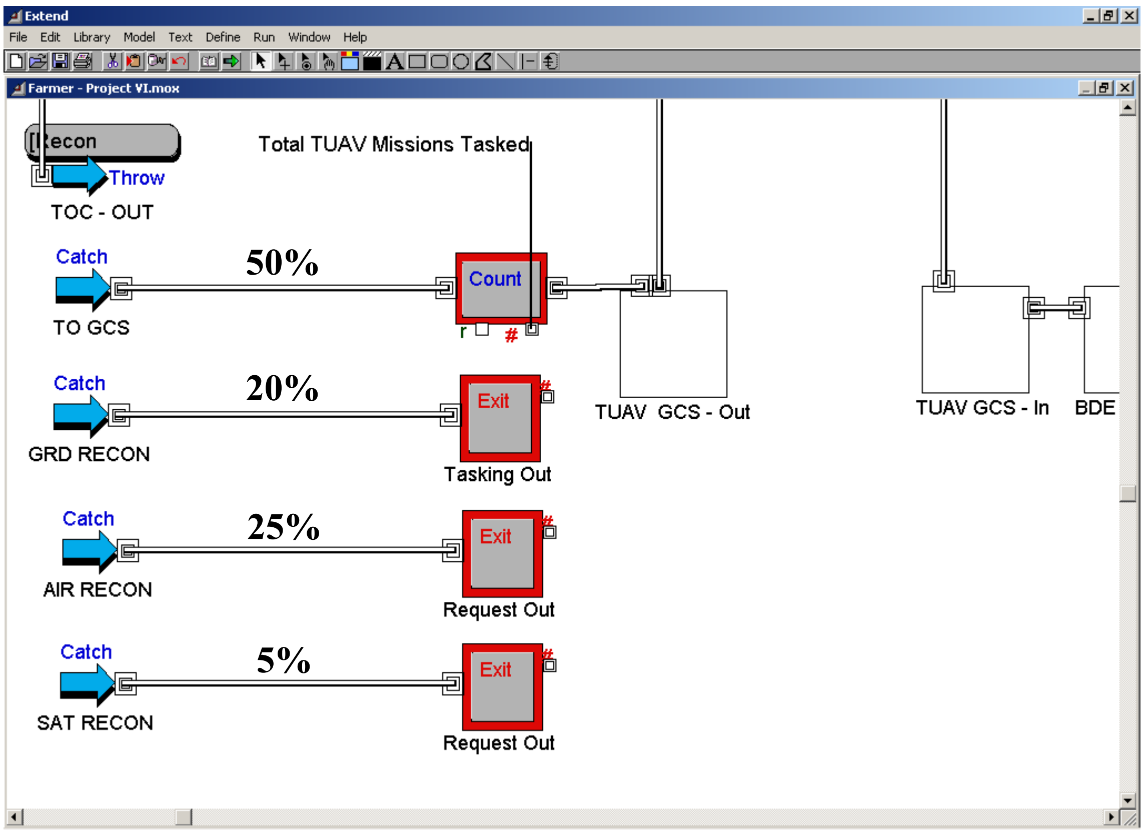

Figure 17. Brigade MTI Follow-up Taskees

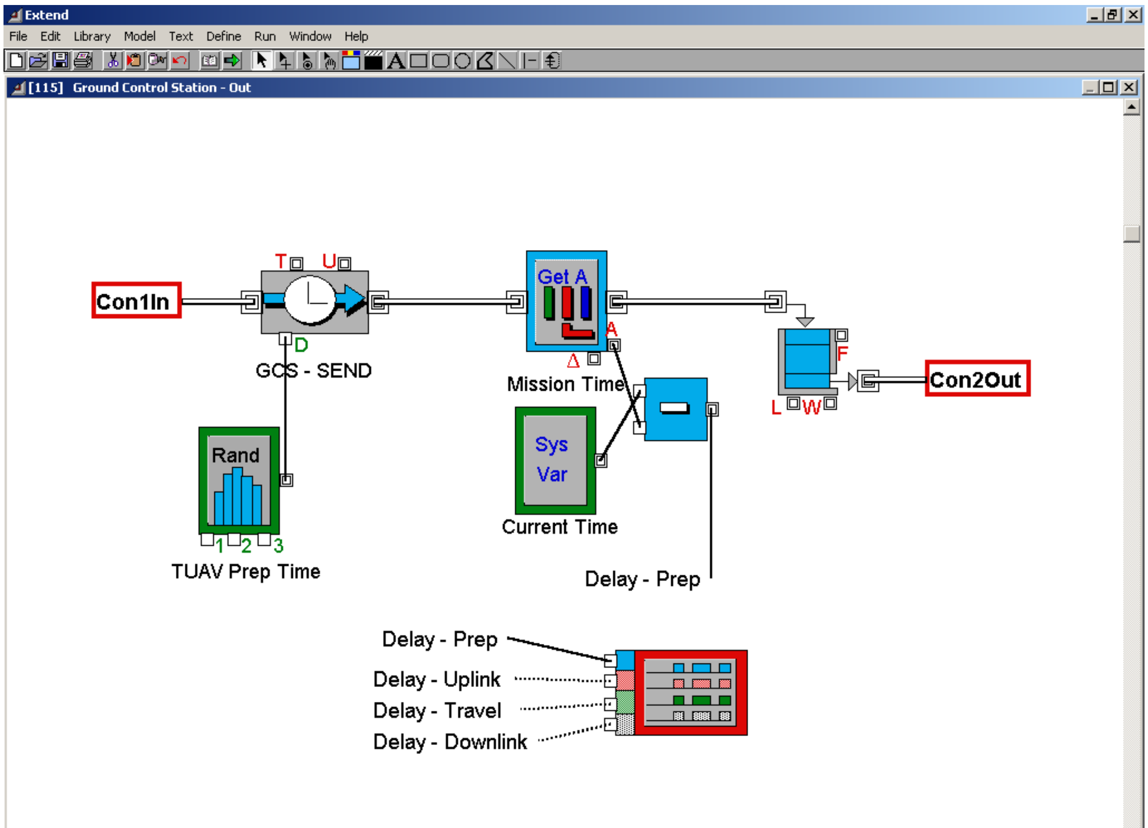

Figure 18. TUAV GCS-OUT Hierarchical Block

5. TUAV – Receive

As the item passes to the "TUAV-RECEIVE" hierarchical block (Fig. 19), the current time is marked, in this case to note the time the command instructions for the new mission were transmitted by the GCS to the AV. The uplink delay between transmission of the command message and its receipt by the AV is captured as the item exits the TUAV Activity Delay block. The item then moves into a FIFO queue.

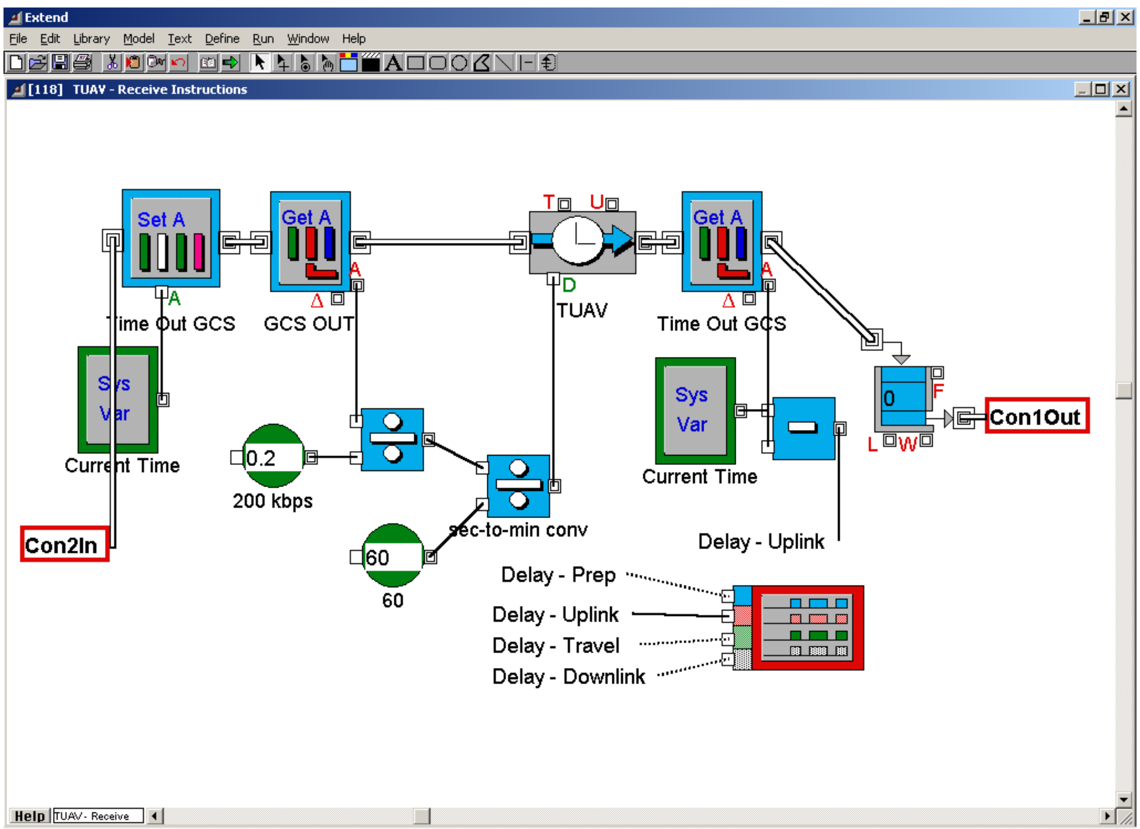

Figure 19. TUAV-RECEIVE Hierarchical Block

6. TUAV – Mission

As the MTI item passes into the "TUAV-MISSON" hierarchical block, the time the AV initially begins traveling to the mission area is captured (Fig. 20). The item moves into the "MISSION-EXECUTE" Activity Delay block where the delay from the TUAV receiving its command instructions to the TUAV arriving in the mission area is applied (the travel delay). The delay is measured as the item moves out of the delay block.

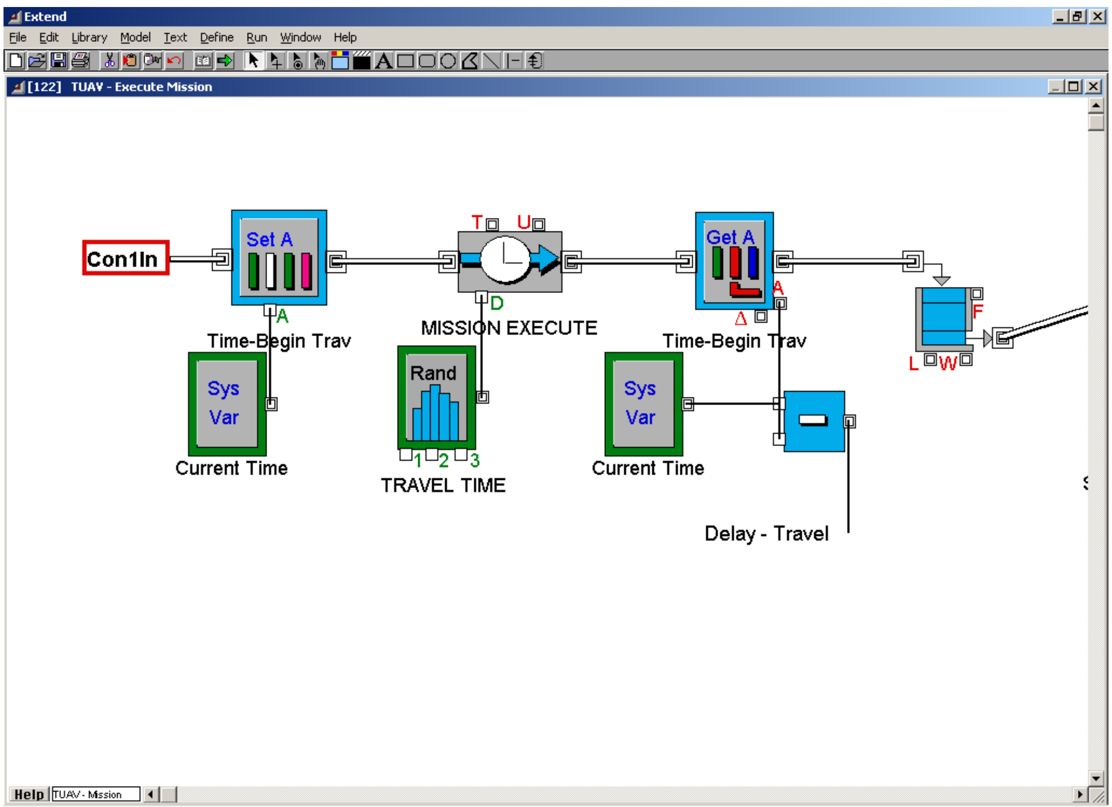

Figure 20. TUAV-MISSION Hierarchical Block, Part I

Once in a position to begin mission execution, i.e., the AV is close enough for the operator to make an identification, the simulation compares the slant range of the MTI to the AV's threshold survivable stand off range (Fig. 21). If the target is outside of this range, the MTI proceeds to transmit imagery to the "TUAV GCS-IN" block. If the slant range is within the survivable stand off range, the AV is potentially "shot down" (based off of empirical table inputs). If not downed, the time that the AV was ready to begin transmitting imagery is captured and the item proceeds in the simulation to the "TUAV GCS-In" block.

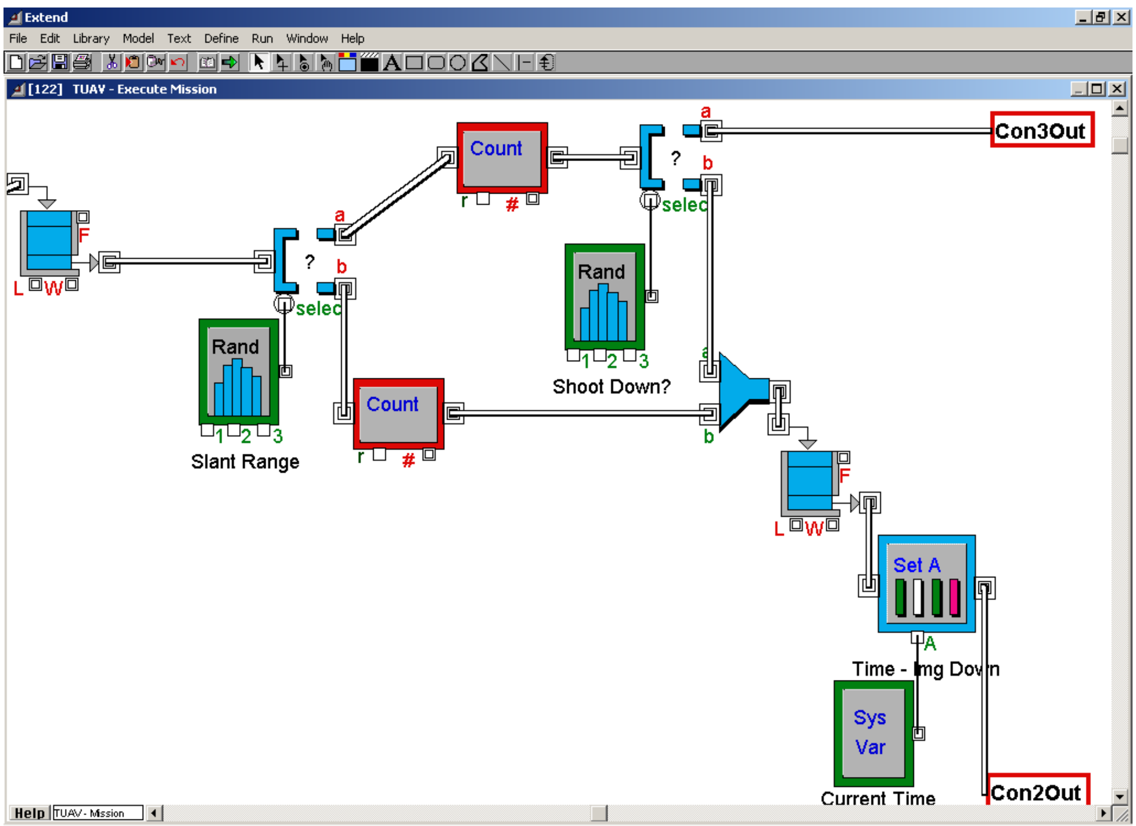

Figure 21. TUAV-MISSION Hierarchical Block, Part II

7. TUAV GCS – In

As the imagery flows along the TCDL to the GCS, it is delayed by the MPEG-2 video size divided by the bandwidth (10.1 Mbps) at the GCS-REC Activity Delay block (Fig. 22). This is the downlink delay measuring the time between the beginning of imagery transmission to receipt at the GCS. As the item exits the GCS-REC block, the downlink delay is measured. The item then proceeds to a FIFO queue and is ready to continue in the simulation.

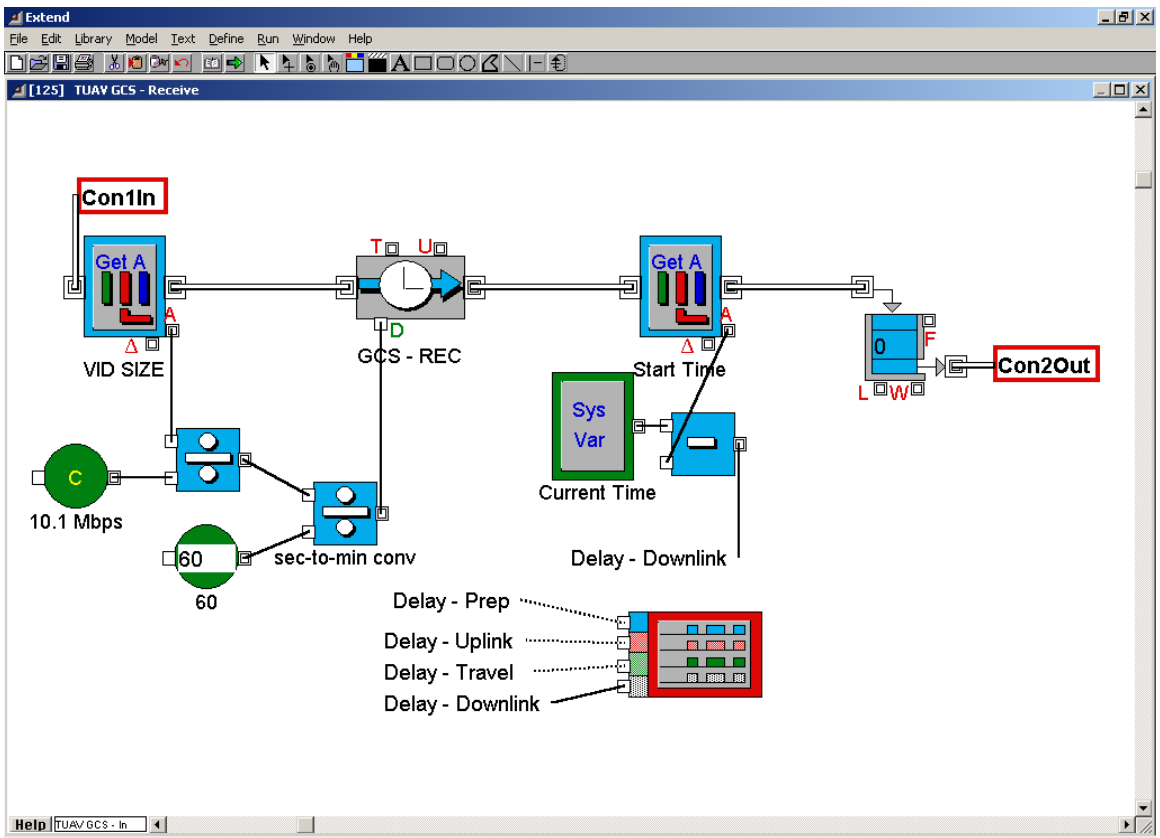

Figure 22. TUAV GCS-IN Hierarchical Block

8. BDE TOC – In

At the "BDE TOC – IN" hierarchical block (Fig. 23) there is a delay of one to five minutes to account for the Brigade decision time – is the target friendly, enemy, or a neutral (the CID) and what COA does the decision-maker take.

A key point – neither the TUAV system, nor any UAV system, can autonomously determine a combat identification. The identification process will always involve a "man in the loop". Whether the identification is made, and if so whether or not the identification is accurate, depends on a number of factors that will be examined later.

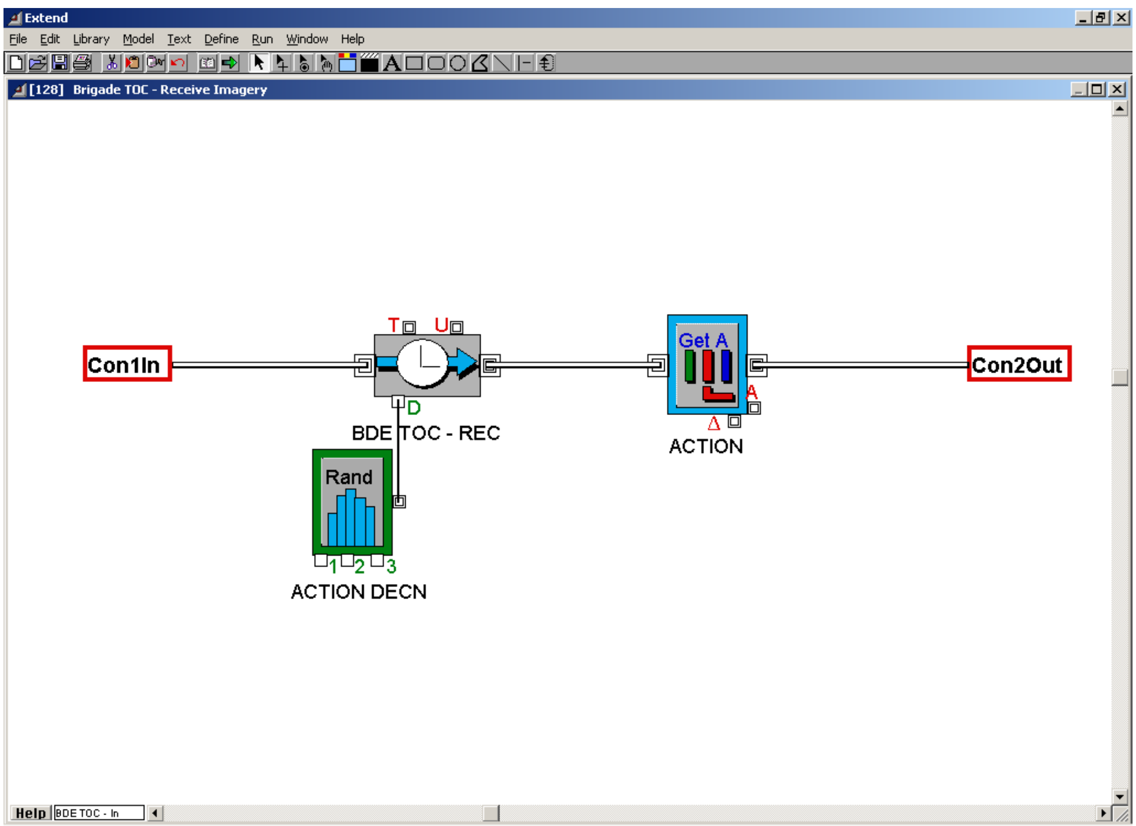

Figure 23. BDE TOC – IN Hierarchical Block

Once the Brigade decides on a COA, the item proceeds in the simulation and the attribute relating to the COA is read. The item then exits the BDE block and enters a Throw block (Fig. 24), where the item will be directed to one of four potential action nodes: alert (do not engage, item is friendly or neutral); engage with indirect fires; engage with direct fires; other (e.g., continue to observe for later decision). The item then exits the simulation. As the item exits, a plotter captures the total number of missions executed off of TUAV imagery, along with total missions assigned to the TUAV system and total number of AVs shot down during mission execution.

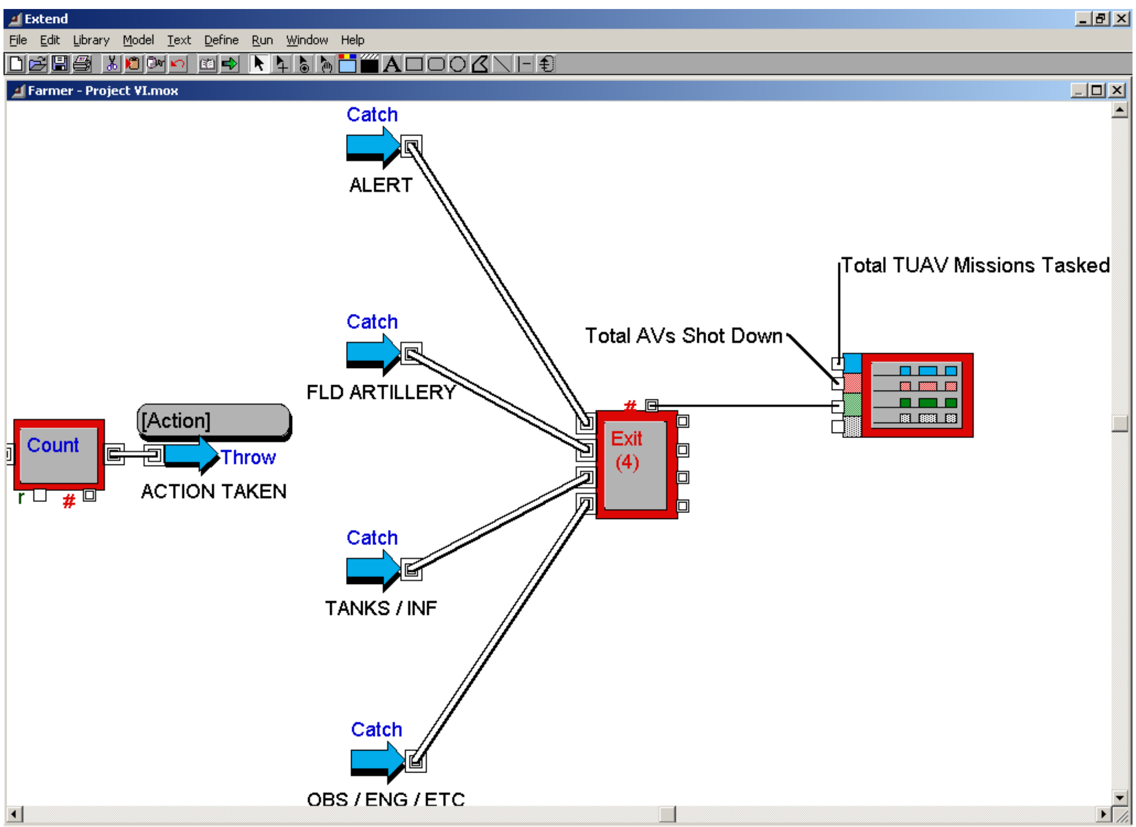

Figure 24. Brigade Action Decision Options

C. MODEL CONFIGURATION

Following are the initial settings for the Extend modeling blocks. System parameters that will not change throughout the testing are labeled "fixed" and their values will not be discussed when adjustments are made to the model.

1. "JSTARS" Generator Block

MTI generation follows an exponential distribution with mean interarrival times of 15 minutes. This means that one MTI item is sent from the JSTARS to the JSTARS CGS every 15 minutes of the simulation.

2. "MTI Message" Input Random Number Variable Block

A real, uniform distribution is used for this variable. The minimum is 0.5 MB, the maximum 10 MB (fixed).

3. "CGS Message" Input Random Number Block

A real, uniform distribution. Values from 0.02 MB to 0.5 MB (fixed).

4. "GCS Out" Input Random Number Block

A real, uniform distribution between 0.002 MB (2 kb) and 1 MB (fixed).

5. "Video Size" Input Random Number Block

MPEG-2 video of 30 to 900 Mb (based on 15 Mb per minute of video and mission durations of two minutes to one hour)(fixed).

6. "Action" Input Random Number Block

An empirical table is used to select one of four possible values: Value 1 (Alert) 30 percent chance of being selected, Value 2 (Indirect Fire) 35 percent, Value 3 (Direct Fire)

25 percent, and Value 4 (Other) 10 percent. The COA is for demonstrative purposes only as the action takes place after the CID decision is made.

7. “CDL” Constant Blocks

10.1 Mbps constant CDL downlink data rate (fixed) and a constant of 60 to convert seconds to minutes.

8. “TACLAN” Constant Block

100 Mbps Tactical LAN data rate (fixed) constant, again with a constant of 60 to convert seconds to minutes.

9. “Decision Time” Input Random Number Block

A real, uniform distribution. Minimum of one minute, maximum of five minutes (fixed). This delay simulates the amount of time it takes the Brigade to decide how they want to develop the MTI item…TUAV, ground reconnaissance, aircraft, or satellite.

10. “Taskee” Input Random Number Block

An empirical table used. Four possible values: Value 1 (TUAV tasking) 50 percent, Value 2 (Ground Recon tasking) 20 percent, Value 3 (Air Recon request) 25 percent, and Value 4 (Satellite Imagery request) five percent.

11. “TUAV Prep” Input Random Number Block

A real, uniform distribution. For the initial simulation, the AV being used is on the ground and will take 15 to 30 minutes to prep, take off, and move towards the mission area.

12. “TCDL Uplink” Constant Blocks

The TCDL uplink rate is 200 Kbps, therefore constant of 0.2 Mbps (fixed), divided by a constant of 60 for second-to-minute conversion.

13. “Travel Time” Input Random Number Block

A real, uniform distribution. Minimum of five minutes and maximum of 30 minutes (fixed).

14. Slant Range Input Random Variable Block

Empirical table input into a Select DE block that simulates the AV being inside or outside the survivable stand off range when it acquires the target (i.e., the operator is able to detect the target). The MTI item will continue through the simulation and the AV will begin transmitting imagery to the GCS 92.5 percent of the time (fixed). This is based off of testing that indicates 92.5 percent detection success of the AV’s Forward Looking Infrared (FLIR) pod outside of the 3 km threshold survivable stand off range. The remainder of the items (7.5 percent) (fixed) will continue to another DE Select Block (“Shoot Down?”).

15. “Shoot Down” Input Random Variable Block

Input from empirical table. Fifty percent of AVs flying inside of the threshold survivable stand off range will be “shot down” and exit the simulation (fixed).

16. “TCDL Downlink” Constant Blocks

The TCDL downlink rate for transmission of MPEG-2 video to GCS is 10.1 Mbps. A constant of 60 is again used for seconds-to-minutes conversion.

17. “Action Decision” Input Random Number Block

A real, uniform distribution of one to five minutes for the Brigade to decide on a COA after reviewing imagery from the TUAV (fixed).

18. Simulation Time

The initial simulation time is 240 minutes to replicate the maximum four hour duration of the Shadow 200 TUAV and assumes (for initial set up) that the AV is on the ground and fully fueled prior to mission start.

19. Discrete Event (DE) Plotters

Plotters are used to display the results of simulation runs. For the four “delay” plotters – prep, uplink, travel, and delay - the vertical axis portrays the applicable delay in minutes and the horizontal axis marks the simulation time (in minutes). For the “totals” plotter, the horizontal axis continues to mark simulation time and the vertical axis measures the three applicable totals – total missions assigned to the TUAV system, total TUAV missions accomplished, and total number of AVs shot down.

D. SCENARIOS MODELED

Three scenarios were developed and modeled for simulation. Each was run for ten iterations and the results captured and analyzed.

1. Scenario 1 – Ground Alert Tasking

In this scenario, the AV is still on the ground at the Launch and Recovery site. No preplanning has occurred for the tasking from Brigade. Variables are set per paragraph C above.

2. Scenario 2 – Immediate Tasking

The AV is already airborne and receives a change of mission based off of a Brigade tasking. The AV prep time variable (previously set to range between 15 and 30 minutes) is lowered to range from one to five minutes. Using an immediate tasking also means the AV has potentially been airborne for an extended period of time. The simulation run time was cut from four hours to three hours to account for this.

3. Scenario 3 – Immediate Tasking with Improved Downlink

No changes from Scenario 2 other than the future planned TCDL downlink rate of 45 Mbps is used in lieu of the current 10.1 Mbps rate.

E. SIMULATION RESULTS

Four system delay plots were drawn for each iteration:

- AV preparation time delay (Prep Delay)
- Uplink delay
- AV travel time delay (Travel Delay)
- Downlink delay

A final plotter measured three items:

- Total number of missions assigned to the TUAV system
- Total number of successfully completed TUAV missions
- Total number of TUAVs shot down

Figure 25 illustrates how an Extend plotter displays data within the simulation. By copying the data at the bottom of the display and pasting it into a spreadsheet program, the data can be manipulated and useful information extracted.

1. Scenario 1 (Iterations 1.1 – 1.10)

Over the course of ten iterations, an average of 7.4 missions were assigned to the

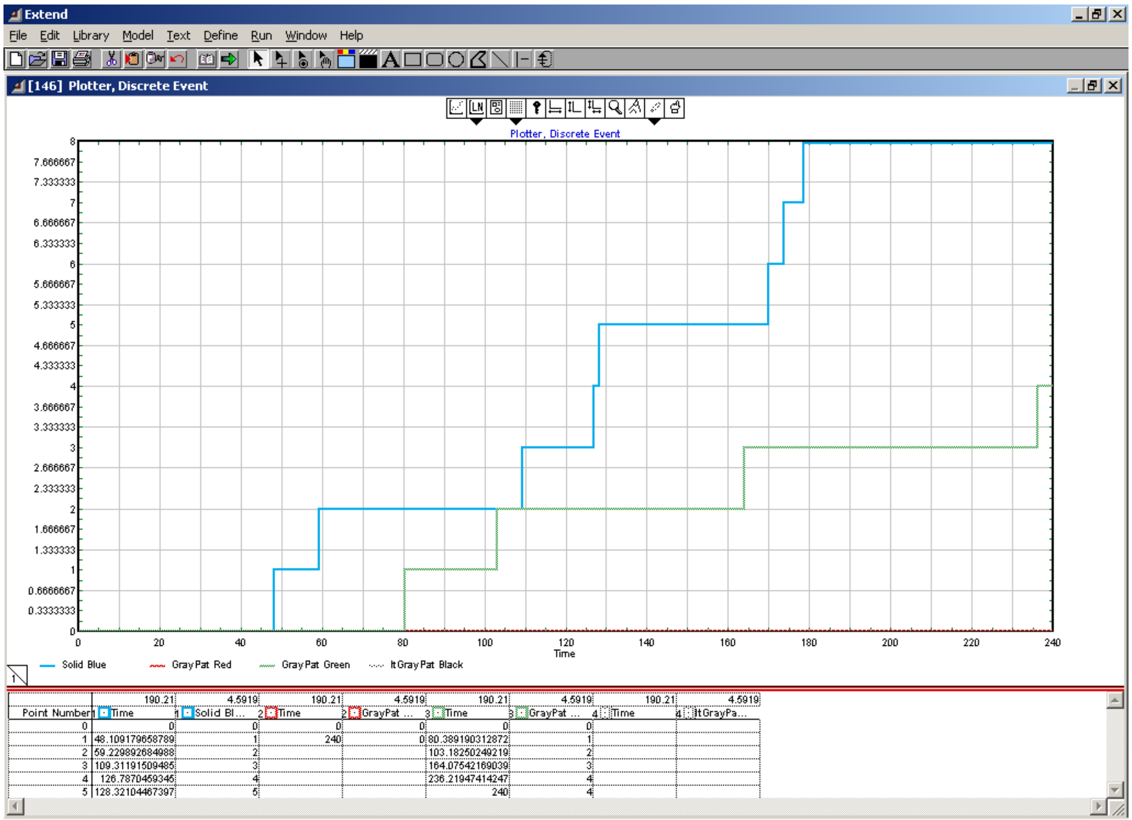

Figure 25. Extend Discrete Event Plotter

TUAV system by the TOC during the four-hour mission windows and 5.6 of these assignments resulted in an AV beaming back imagery resulting in successful CID and an action decision (Fig. 26). In just under seven percent of the iterations, an AV was downed after flying inside survivable stand off range.

The percentage of missions completed ranged from a low of 50 percent to a high of 90 percent, averaging 75.7 percent over the course of the ten iterations. As shown in Figure 27, two types of delays were by far the most significant in Scenario 1 – prep delays (accounting for 58.7 percent) and travel delays (39.4 percent). Delays caused by the uplink and downlink proved insignificant throughout the scenario, averaging 2.4 and 48 seconds, respectively. Combined, the link delays were less than two percent of the overall delays. The individual results for each of the Scenario 1 iterations can be seen in Appendix A.

Overview of Scenario 1 Results

	MISSION											
MISSION OVERVIEW	**1.1**	**1.2**	**1.3**	**1.4**	**1.5**	**1.6**	**1.7**	**1.8**	**1.9**	**1.10**	**TOTAL**	**AVG**
Assigned	11	4	9	7	5	5	10	6	9	8	74	7.4
Successful												
Total	7	2	8	6	4	4	8	5	7	5	56	5.6
%	0.636	0.500	0.889	0.857	0.800	0.800	0.800	0.833	0.778	0.625	0.757	
AVs Shot Down												
Total	1	0	0	0	0	1	1	0	1	1	5	0.5
%	0.091	0.000	0.000	0.000	0.000	0.200	0.100	0.000	0.111	0.125	0.068	
Incomplete												
Total	3	2	1	1	1	0	1	1	1	2	13	1.3
%	0.273	0.500	0.111	0.143	0.200	0.000	0.100	0.167	0.111	0.250	0.176	

	MISSION									
DELAYS OVERVIEW	**1.1**	**1.2**	**1.3**	**1.4**	**1.5**	**1.6**	**1.7**	**1.8**	**1.9**	**1.10**
Total Time of Delays	385.68	123.09	347.62	278.16	154.17	140.40	375.15	245.88	347.02	267.28
Prep										
Total	214.85	74.48	225.72	179.14	88.31	87.97	203.45	132.67	187.53	159.55
Avg	21.49	24.83	25.08	25.59	22.08	17.59	22.61	22.11	23.44	22.79
% of Total Delays	0.557	0.605	0.649	0.644	0.573	0.627	0.542	0.540	0.540	0.597
Uplink										
Total	0.53	0.07	0.31	0.31	0.18	0.25	0.39	0.26	0.35	0.22
Avg.	0.05	0.02	0.03	0.04	0.05	0.05	0.04	0.04	0.04	0.03
% of Total Delays	0.001	0.001	0.001	0.001	0.001	0.002	0.001	0.001	0.001	0.001
Travel										
Total	164.28	46.96	114.51	93.63	61.01	50.01	166.38	108.80	153.30	103.81
Avg.	18.25	23.48	14.31	15.61	15.25	10.00	18.49	21.76	19.16	17.30
% of Total Delays	0.426	0.381	0.329	0.337	0.396	0.356	0.444	0.442	0.442	0.388
Downlink										
Total	6.03	1.59	7.08	5.08	4.67	2.16	4.93	4.14	5.84	3.71
Avg.	0.75	0.79	0.89	0.85	1.17	0.54	0.62	0.83	0.83	0.74
% of Total Delays	0.016	0.013	0.020	0.018	0.030	0.015	0.013	0.017	0.017	0.014

* All delays measured in minutes

Figure 26. Overview of Scenario 1 Results

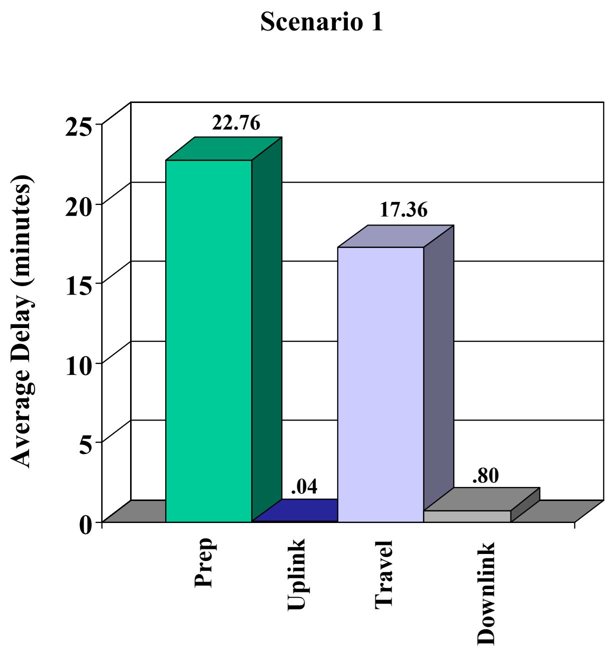

Figure 27. Scenario 1 Average Delays

2. Scenario 2 (Iterations 2.1 – 2.10)

Over the course of ten iterations, an average of 4.8 missions were assigned to the TUAV system by the TOC and 4.1 of these assignments resulted in an AV beaming back imagery resulting in successful CID and an action decision (Fig. 28). There was little change in the shootdown rate from Scenario 1 – again just under seven percent of the AVs were shot down after flying inside survivable stand off range.

Overview of Scenario 2 Results

	MISSION											
MISSION OVERVIEW	**2.1**	**2.2**	**2.3**	**2.4**	**2.5**	**2.6**	**2.7**	**2.8**	**2.9**	**2.10**	**TOTAL**	**AVG**
Assigned	6	5	5	7	5	4	3	3	6	4	48	4.8
Successful												
Total	6	5	5	7	3	3	2	2	5	3	41	4.1
%	1.000	1.000	1.000	1.000	0.600	0.750	0.667	0.667	0.833	0.750	0.854	
AVs Shot Down												
Total	0	0	0	0	2	0	0	1	0	0	3	0.3
%	0.000	0.000	0.000	0.000	0.400	0.000	0.000	0.333	0.000	0.000	0.063	
Incomplete												
Total	0	0	0	0	0	1	1	0	1	1	4	0.4
%	0.000	0.000	0.000	0.000	0.000	0.250	0.333	0.000	0.167	0.250	0.083	

	MISSION									
DELAYS OVERVIEW	**2.1**	**2.2**	**2.3**	**2.4**	**2.5**	**2.6**	**2.7**	**2.8**	**2.9**	**2.10**
Total Time of Delays	118.63	125.15	76.67	136.16	118.32	129.78	52.45	54.74	103.14	58.26
Prep										
Total	18.30	15.10	10.43	20.39	15.17	12.18	6.98	9.70	19.19	11.25
Avg	3.05	3.02	2.09	2.91	3.03	3.04	3.49	3.23	3.20	2.81
% of Total Delays	0.154	0.121	0.136	0.150	0.128	0.094	0.133	0.177	0.186	0.193
Uplink										
Total	0.26	0.23	0.20	0.35	0.24	0.22	0.13	0.12	0.28	0.12
Avg.	0.04	0.05	0.04	0.05	0.05	0.06	0.07	0.04	0.05	0.03
% of Total Delays	0.002	0.002	0.003	0.003	0.223	0.002	0.002	0.002	0.003	0.002
Travel										
Total	95.16	104.77	62.28	108.70	100.30	113.28	44.34	43.58	78.35	43.98
Avg.	15.86	20.95	12.46	15.53	20.06	28.32	22.17	14.53	15.67	14.66
% of Total Delays	0.802	0.837	0.812	0.798	0.848	0.873	0.845	0.796	0.760	0.755
Downlink										
Total	4.91	5.05	3.76	6.72	2.62	4.09	1.01	1.34	5.31	2.91
Avg.	0.82	1.01	0.75	0.96	0.87	1.02	0.50	0.67	1.06	0.97
% of Total Delays	0.041	0.040	0.049	0.049	0.022	0.032	0.019	0.025	0.051	0.050

* All delays measured in minutes

Figure 28. Overview of Scenario 2 Results

The percentage of successful missions increased substantially from Scenario 1, ranging between 60 and 100 percent, with an average completion rate of 85 percent. With this scenario's change, lowering the prep time from 15-30 minutes to one-five minutes, the prep time delay lowered markedly, from almost 60 percent of the delays in Scenario 1 to 14.7 percent of the delays in Scenario 2. Travel time accounted for most of the delays (Fig. 29), averaging 81.3 percent of total delays over the ten iterations of Scenario 2. Again, uplink and downlink delays were very small in the overall scheme. While their percentages as part of the overall delays increased slightly, the average time per link delay increased by less than three seconds. The results for the ten Scenario 2 iterations can be seen in their entirety in Appendix B.

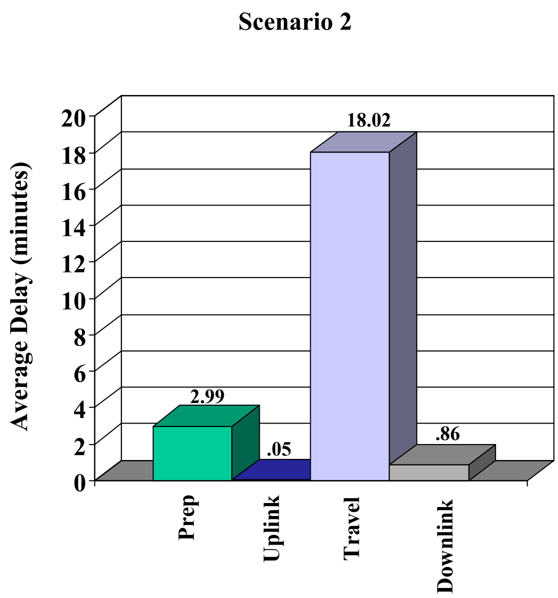

Figure 29. Scenario 2 Average Delays

3. Scenario 3 (Iterations 3.1 – 3.10)

Increasing the downlink data rate in Scenario 3 (from 10.1 Mbps to 45 Mbps) lowered the average downlink delay from 51.6 seconds to 10.2 seconds. The only other significant change was a 50 percent reduction in the shootdown rate, from just over six percent to just over three percent (Fig. 30). The Scenario 3 individual results can be viewed in Appendix C.

Overview of Scenario 3 Results

	MISSION											
MISSION OVERVIEW	**3.1**	**3.2**	**3.3**	**3.4**	**3.5**	**3.6**	**3.7**	**3.8**	**3.9**	**3.10**	**TOTAL**	**AVG**
Assigned	6	9	5	3	7	10	7	5	5	5	62	6.2
Successful												
Total	5	8	5	3	6	8	6	5	4	5	55	5.5
%	0.833	0.889	1.000	1.000	0.857	0.800	0.857	1.000	0.800	1.000	0.887	
AVs Shot Down												
Total	0	1	0	0	1	0	0	0	0	0	2	0.2
%	0.000	0.111	0.000	0.000	0.143	0.000	0.000	0.000	0.000	0.000	0.032	
Incomplete												
Total	1	0	0	0	0	2	1	0	1	0	5	0.5
%	0.167	0.000	0.000	0.000	0.000	0.200	0.143	0.000	0.200	0.000	0.081	

	MISSION									
DELAYS OVERVIEW	**3.1**	**3.2**	**3.3**	**3.4**	**3.5**	**3.6**	**3.7**	**3.8**	**3.9**	**3.10**
Total Time of Delays	79.89	148.56	101.70	45.87	127.20	172.76	104.27	120.65	79.81	61.91
Prep										
Total	17.34	22.85	13.84	6.78	24.62	29.17	21.87	13.23	13.56	8.19
Avg	2.89	2.54	2.77	2.26	3.52	2.92	3.12	2.65	2.71	1.64
% of Total Delays	0.217	0.154	0.136	0.148	0.194	0.169	0.210	0.110	0.170	0.132
Uplink										
Total	0.23	0.30	0.19	0.07	0.21	0.37	0.28	0.31	0.20	0.13
Avg.	0.04	0.03	0.04	0.02	0.03	0.04	0.04	0.06	0.04	0.03
% of Total Delays	0.003	0.002	0.002	0.002	0.002	0.002	0.003	0.003	0.002	0.002
Travel										
Total	61.77	123.70	86.65	38.63	101.51	141.63	81.25	106.41	65.09	52.55
Avg.	12.35	13.74	17.33	12.88	14.50	17.70	13.54	21.28	16.27	10.51
% of Total Delays	0.773	0.833	0.852	0.842	0.798	0.820	0.779	0.882	0.816	0.849
Downlink										
Total	0.55	1.72	1.02	0.39	0.85	1.59	0.88	0.69	0.97	1.04
Avg.	0.11	0.22	0.20	0.13	0.14	0.20	0.15	0.14	0.24	0.21
% of Total Delays	0.007	0.012	0.010	0.008	0.007	0.009	0.008	0.006	0.012	0.017

* All delays measured in minutes

Figure 30. Overview of Scenario 3 Results

Prep and uplink delays remained relatively constant, averaging 3.0 minutes and 2.7 minutes, respectively. The average travel delay, the longest type of delay in Scenario 3 (Fig. 31), increased approximately one minute. Downlink delays, which in Scenario 2 averaged .86 minutes (50 seconds) each, were down to .17 minutes (10.2 seconds) each, a five-fold decrease. Appendix C contains the results for the ten Scenario 3 iterations.

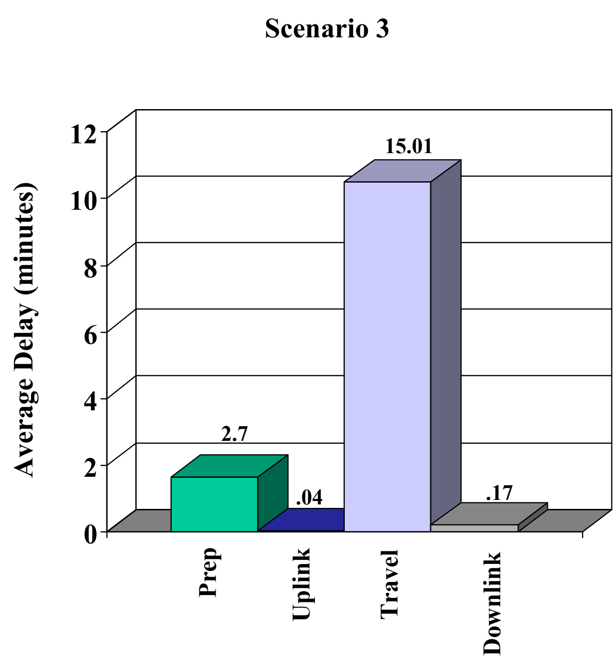

Figure 31. Scenario 3 Average Delays

F. SIMULATION CONCLUSIONS

This simulation was used as a process model to determine possible improvements that could be made in the TUAV system if it is to be used as a CID tool. From a technological standpoint, can the system aid ground forces in determining whether or not to pull a trigger? The bottomline answer is yes, the simulation showed that a single TUAV system can aid in multiple CID decisions during a single mission. The primary factors in the TUAV's timeliness as a CID tool were the amount of time to prep the AV for the mission and the travel time for the AV to reach the target area (Fig. 32). By decreasing the length of these delays, the system's ability to function as a useful CID tool at the tactical level will be greatly enhanced. Detailed simulation observations follow.

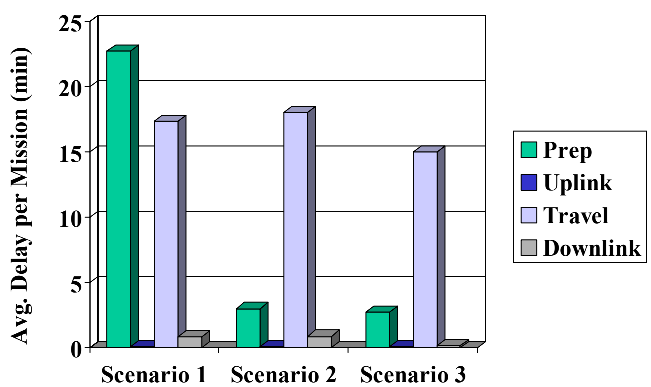

Figure 32. Overall Simulation Average Delays Per Mission

1. Taskees

It is obvious that a given TUAV system can handle only so many tasking (whether CID taskings or some other type of reconnaissance mission) during its mission window. For the simulation the system received 50 percent of the MTI items that needed further reconnaissance. Another option is to task a greater percentage of MTI follow-ups to ground reconnaissance elements – whether they be from the Brigade's Reconnaissance Troop, Battalion Scout Platoons, or mechanized units subordinate to the Brigade – or requesting aerial reconnaissance or satellite imagery from outside agencies not subordinate to the Brigade (and thus not as responsive). Tasking the ground elements for a large number of reconnaissance tasks above and beyond their currently assigned missions is generally not a good idea. In particular the Reconnaissance Troop and the Scouts are inherently overtasked to begin with. Possible solutions will be addressed in conclusions and recommendations.

2. AV Prep Time

AVs on the ground prior to mission tasking took an average of 20 minutes longer to prepare for the mission than those receiving an immediate tasking while airborne. On top of the quicker response time, using a "hot" AV has the additional benefit of putting the AV closer to the mission area when it receives the tasking (as the L/R Site is located five to ten kilometers behind the TOC area in most tactical situations). On the downside, an immediate tasking to the AV may take it away from a critical mission that the commander wants accomplished. The bottomline - before retasking an AV, the criticality of saving a few minutes in getting the new target's imagery to the TOC must be weighed against potential impacts to the current mission plan.

3. Uplink Delays

The 200 Kbps uplink rate proved satisfactory throughout the simulation.

4. Travel Delays

Travel delays averaged between 15 and 20 minutes per assigned mission. This was the largest type of delay experienced in the simulation during the "immediate tasking" types of missions where the AV was already airborne. It is clear that the number of CID missions the Brigade can accomplish with a given AV during its mission window is very dependent on how wisely the Brigade decision makers manage their assets. An example of good asset management would be to task a mechanized company in the vicinity of a questionable MTI to investigate the unknown target rather than tasking an AV that is ten kilometers away and in the process of carrying out a planned reconnaissance and security (R&S) mission.

5. Shoot Downs

In Scenarios 1 and 2, the shoot down rate of AVs ranged between six and seven percent. In these shoot downs, the AVs had to get too close to the target in order for an operator to make a CID decision. This rate of loss may sound high, but keep in mind that seven Army Hunter UAVs, almost half of the Hunters in the theater, were shot down by the Yugoslavians or crashed during NATO's Operation Allied Force 78-day air war in 1999 [Ref. 13].

In Scenario 3, when the downlink rate was changed from the current 10.1 Mbps to the planned 45 Mbps, the shoot down rate dropped to just over three percent. It appears that AV survivability is enhanced by the quicker imagery download rate – less loiter time equals less shoot downs.

Another observation in this area deals with CID training. The AVs resolution is sufficient that it should not need to get within threshold survivable stand off in order for an identification to be made. The primary remedy for this is operator CID training, which will be discussed in conclusions and recommendations.

6. Downlink Delays

While the downlink delays throughout the simulation were not significant as a whole, it was clear that once the rate is increased from the current 10.1 Mbps to the planned 45 Mbps, a significant cut will be made in these types of delays. On average, the delays decreased by almost 40 seconds per assigned mission. Not only can this make a difference in the AVs survivability, but also it increases the number of missions that the AV can perform during its mission window.

A way to reduce this delay even further, regardless of which downlink rate is used, is through operator CID training. The faster an imagery analyst makes an identification, the less time before the GCS AV operator can move the AV from the target area. The amount of time saved is dependent on where the imagery analyst making the CID is located. If he is at the Brigade TOC and the TOC is collocated with the GCS, the amount of loiter time cut will be greater than if the CID is made by someone at an RVT who has to send the ID over a radio.

Finally, we should not neglect the fact that other systems will likely be tied into the Tactical Common Data Link used by the TUAV. Keeping the amount of imagery down and increasing the link's data rate will help the TCDL from being over-saturated with electronic traffic.

7. Action Decision Delays

These delays were not measured in the simulation because they were so small – set for a one to five minute delay. One to five minutes is an adequate amount of time for trained personnel to make a COA decision given the proper target resolution. If a unit places inexperienced people in the position to make these calls, one or more things will happen – the time needed for identification will increase, the possibility of making the wrong CID call escalates, and/or an AV will be shot down as operators have to bring the Shadows too close to an unfriendly target for a better look.

IV. ASCIET 2000 EVALUATION OBSERVATIONS

This chapter describes UAV-specific observations made during the All Service Combat Identification Team (ASCIET) evaluation conducted 28 February through 10 March 2000 at Fort Stewart, Georgia. Renamed in late 2000 as the Joint Combat Identification Team (JCIET), JCIET is based at Eglin Air Force Base, Florida and is part of Joint Forces Command. JCIET is responsible for testing the equipment, methods, and engagement tactics of the four branches of the U.S. armed forces to learn how well they avoid the problem of mistaking friendly forces for the enemy. It addresses the high level fratricide concerns brought about by the increased emphasis on joint warfare operations and the fielding of weapons and sensor systems operating beyond visual range, at night, and in adverse weather conditions.

JCIET accomplishes their mission through the conduct of annual evaluations that bring together representative units and equipment from each of the services' ground, missile, and aviation communities for a two week joint tactical scenario involving the Ground to Ground, Ground to Air, Air to Ground, and Air to Air mission areas. All mission area players are heavily instrumented. At the conclusion of the evaluation, JCIET examines the tactics, techniques, and procedures (TTPs) used by the units, along with the data JCIET analysts extrapolate through the instrumentation, and makes recommendations on possible ways of improving CID in the joint arena.

The UAV system utilized during ASCIET 2000 was the Hunter UAV. While this is a different system than the Shadow 200 used as the Brigade's TUAV, the observations that follow are not system-specific, but are observations on the Army and Marine units' use of UAVs during the eval.

A. INTEGRATION

Steve Mecham of SAIC, JCIET's lead UAV analyst, noted that the most eye–opening observations on UAV use in ASCIET 2000 lay in integration [Ref. 14]. While both the Army and Marines present at the evaluation were sold on the UAVs use in support of the tactical commander, neither force was able to fully integrate the UAV into the current operation. TTPs for the UAVs use as both a surveillance and fire support tool need to be worked out in advance to maximize the system's potential, and this did not happen.

B. REPORTING

The JCIET Staff noted duplicate or contradictory report generation on several occasions during ASCIET 2000. The primary reason for this erroneous reporting was multiple people looking at the same imagery feed from different locations - from ground control stations as wells as at remote video terminals passed down to the battalion headquarters. Different "analysts" at different imagery reception nodes would report on the same target (resulting in multiple reports) or send differing information about the same target regarding direction of movement, type, etc., resulting in contradictory reports. This was primarily a breakdown in reporting procedures, a topic that will be dealt with in the conclusions and recommendations section.

C. REMOTE VIDEO TERMINAL (RVT) USE AT SUB-UNIT LEVEL

Both the Marine and Army higher headquarters sent RVTs to subordinate battalions for their use during ASCIET 2000. The comments from the sub-units' Battalion Intelligence Officers (S2s) were similar. Both noted that information derived from UAV reports received from their higher headquarters was often more useful than the imagery they were receiving near real time on the supplied RVTs. Both units also stated that they lacked the manpower and the expertise to properly man the RVTs. As noted earlier, the battalions also had reports of movement duplicated at the Battalion, Brigade, and Joint Task Force levels.

Dr. Scott Ritchey noted that during the first week of the evaluation, no one in the Marine Air Ground Task Force (MAGTF) Intelligence tent looked at the UAV display [Ref. 15]. Personnel were functioning as they were trained, and their training did not include stewardship of the UAV display. After the first week, a Marine NCO rearranged the floor plan, grouping the Generic Area Limitation Environment (GALE-LITE), UAV display, and JSTARS Remote Workstation (RWS) display together in a corner. Both the GALE-LITE and RWS had dedicated, assigned, trained operators. As there was not a great deal of SIGINT activity, the GALE operator began looking at the UAV display out of boredom, becoming the de facto imagery analyst and made good use of the UAV after a freeze-picture capability was added [Ref. 16].

D. INABILITY TO MAKE COMBAT IDENTIFICATION

Mecham noted that only about 35 percent of UAV detections (by personnel viewing the video in multiple nodes) were actually identified. Dr. Ritchey made a similar observation in the MAGTF COC. Less than ten percent of the detections resulted in the generation of a fire mission or support to a Close Air Support (CAS) mission. Why the difficulty in identifying a detected target? It was not an imagery resolution issue, but rather an inability on the part of analysts to tell one type of vehicle from another. This is a training shortfall and is further addressed in the following section. Possible solutions will be discussed in conclusions and recommendations.

E. OPERATOR VEHICLE IDENTIFICATION TRAINING

Most of the Intel analysts are not trained to exploit thermal imagery. The best thermal imagery analysts were the personnel who used it everyday – the tank and fighting vehicle crewmen. Unfortunately, putting these personnel in front of a TUAV imagery display means they are not carrying out the jobs they are trained to do – closing with and destroying the enemy.

F. INITIAL AVERSION TO INFRARED (IR) MODE

Players did not use the thermal channel until the first night mission (occurring in Week 2 of the evaluation). It was obvious that the personnel acting as imagery analysts felt much more comfortable viewing the EO imagery, a pure daylight view. Because they had preconceived ideas that "thermal is hard", they felt that the UAV would not be useful at night. They later admitted they were very wrong on that score. The analysts were so impressed by the thermal imagery once they began using it during the second week that IR became their primary mode of operation for both day and night operations.

The imagery analysts, most of them trained SIGINT analysts temporarily assigned to man the UAV stations, quickly learned thermal identification features. They found that IR was excellent for cueing, and they were able to select potential targets (hot spots) much quicker than they had been able to in EO mode. The thermal mode also enabled analysts to detect and identify targets under thin tree cover. This would have been impossible in EO mode. During some follow-on daylight missions, analysts began switching between EO and IR modes, using IR the majority of the time, but occasionally switching to the EO channel to capitalize on its superior resolution to identify target details for those vehicles operating in the open.

G. AIR-TO-SURFACE COMBAT I.D. PANEL (CIP)

Dr. Ritchey made an interesting observation while analyzing UAV imagery after one mission – a distinctive thermal signature on a vehicle [Ref. 16]. It was a high-contrast, rectangular cold spot (therefore white) on the back deck of a vehicle. Figure 33 is a photo of the vehicle (second in column). Subsequent investigation found this vehicle to be a Russian BMP Infantry Fighting Vehicle and that the cold spot was a drip pan lashed to the BMPs aft deck with bungee cords.

Figure 33. Hunter UAV IR Shot of Drip Pan on Rear Deck of BMP [From: Ref. 16]

Figures 34 and 35 are close-ups of the drip pan. It was purchased at a NAPA auto parts store (Part number BK 811-4000) and appears to be zinc electro-plate with a thin film of dirt. The conclusion was that the drip pan acted as an upward-facing CIP, reflecting the cool sky and thus producing a “cold spot”.

Figure 34. Top View of Drip Pan [From: Ref. 16]

Figure 35. Rear View of Drip Pan [From: Ref. 16]

V. CONCLUSIONS AND RECOMMENDATIONS

A. CONCLUSIONS

The results of the Extend simulation, the Shadow 200 tests conducted to date by the Army, and the observations made by JCIET during its evaluations support that the Tactical Unmanned Aerial Vehicle system can aid the tactical commander as a CID tool.

While the simulation results support the TUAVs ability to aid in CID, there are still areas where improvement can be made if the system is to live up to its full potential. The following issues should be addressed not only to aid units' CID efforts, but also if the TUAV is to in fact become the ground maneuver commander's primary day/night Reconnaissance, Surveillance, and Target Acquisition (RSTA) system. Additionally, many of these conclusions, as well as the recommendations that follow, are applicable to Marine Corps UAV usage at the tactical level, regardless of which system they field.

1. Vehicle Identification Training

The amount and level of vehicle identification training (particularly thermal identification training) needs to be increased for all imagery analysts.

2. Integration

The TUAV system should be integrated with other currently available CID equipment.

3. Surface-to-Air CID Panel

The Army and Marine Corps ground forces need a Surface-to Air combat identification panel to serve as a thermal ID recognition feature to AV imagery analysts, as well as to helicopter and close air support crews.

4. TUAV Planning and Mission Execution

Brigade staffs must ensure the TUAV's use as a CID tool is planned in conjunction with the commander's reconnaissance and surveillance plan for proper mission integration, as well as ensure that the TUAV's use during mission execution falls within the Commander's Intent.

5. Automation in the CID Process

DoD should increase research that will reduce or remove the "man in the loop" in the imagery analyses process. The most likely method of accomplishing this is through the use of synthetic aperture radar (SAR) and Automatic Target Recognition (ATR).

SAR sensors can image ground targets at extremely high resolutions and long ranges, through clouds and in darkness. The SAR takes a series of low-resolution images in sequence. These images are then synthetically combined to give a high-resolution product. We see that each object has a unique "signature". ATR is the process of using a computer to assist in identifying which features in a scene indicate a target's presence. When combined, these technologies would be able to cue analysts to areas of interest, reducing the time required for them to review each image. A very robust ATR system that includes an identification algorithm could identify and locate targets without operator intervention and with low false alarm rates.

The Defense Advanced Research Project Agency (DARPA) is currently working a project called Moving and Stationary Target Acquisition and Recognition (MSTAR) [Ref. 17]. MSTAR will identify tactical and strategic targets in SAR imagery. While DARPA, as well as other agencies, institutions, and corporations, have made major strides in ATR and its application in the visible domain, millimeter wave (MMW) radar, laser radar, SAR, and other sensors, the technology is not yet present to even semi-automate the CID process. Despite the tremendous increase in computing power in recent years, the major technical challenge remains – the development of robust algorithms (single and multi-sensor) to deal with variations in target signatures (e.g., stores, articulation, manufacturing, system wear and tear), target acquisition parameters (e.g., aspect, depression, squint angles), target phenomenology (e.g., cavity responses, glints, IR thermal behavior), and target/clutter interaction (e.g., foliage masking, camouflage). An additional challenge is to develop the algorithms such that they maintain low false alarm rates and operate in real time. One of the more promising SAR/ATR systems will be examined further in the recommendations section.

But another question must be answered as well in regard to ATR – assuming we develop a dependable, low false alarm rate ATR system that can operate in real time/near real time, to what extent should the CID process be automated? This issue will be discussed in the recommendations section as well.

B. RECOMMENDATIONS

The following recommendations are tied to the conclusion in paragraph A above.

1. Use of ROC-V Software for Thermal Vehicle Recognition Training

Recognition of Combat Vehicles (ROC-V), sponsored by the Army's Product Manager Forward Looking Infrared Radar (PM FLIR) and developed by the Night Vision and Electronic Sensors Directorate (NVESD) at Fort Belvoir, Virginia, is a multimedia-based software package contained on a single CD ROM that teaches users thermal vehicle recognition. The system requirements of a 133 Mhz Pentium PC/laptop with Windows 95 and a CD ROM are basic enough that training can be conducted anywhere from the unit training room to field or float locations. ROC-V version 7.0 is compatible with Windows 95, 98, NT, ME, and 2000 and includes two CDs – one for training units equipped with the older thermal imaging systems and one for training units equipped with the new Second Generation FLIR.

ROC-V utilizes an extensive database of real thermal images to teach and test the signatures 47 U.S. and non-U.S. vehicles (Figs. 36 through 38). Training includes teaching the user unique hot spot shapes and locations of engines and exhausts as well as the geometric vehicle cues. This software is a vast improvement over using flash cards, etc., as training aids - particularly where thermal ID training is involved.

A shortfall in using ROC-V to train UAV operators on vehicle ID is a lack of "top down" imagery as would be seen from an AV. Because the distinctive thermal signatures of different vehicle types do not change regardless of the operator's view, training imagery analysts with the current version of ROC-V would still have some usefulness. With that said, however, I would recommend incorporation of top-down imagery for the vehicles in the current ROC-V database. This would not only aid in the training of UAV operators and analysts, but also has potential training value for helicopter crewmen.

2. Integration of Combat Identification Systems

Dr. Stephen Wiener of The MITRE Corporation suggests that if we are looking at two technologies to fill the CID role, perhaps neither can do the job satisfactorily by itself [Ref. 18]. By combining two CID technologies, a synergistic affect may be attained.

A concept being examined by PM CI is to equip UAVs with an MTI radar and a Battlefield Combat Identification System (BCIS) – this could be one of the modular payloads for a TUAV system. The AV relays to the TUAV GCS the coordinates of moving vehicles on the battlefield and which of those vehicles have responded to the BCIS query. Looking at his display at the GCS, the AV operator can see the coordinates of confirmed friendly vehicles and the coordinates of any "unidentified vehicles" in the vicinity.

A possible improvement on this idea would be to continue using a wide area sensor such as JSTARS for cueing and for the AV to have a combination of EO/IR and BCIS capabilities. This could present a problem with the current TUAV system due to payload weight restrictions, but could likely be planned for future systems, particularly the more robust Division and Corps TUAV systems that are the next step in developing the TUAV family of systems for the Army.

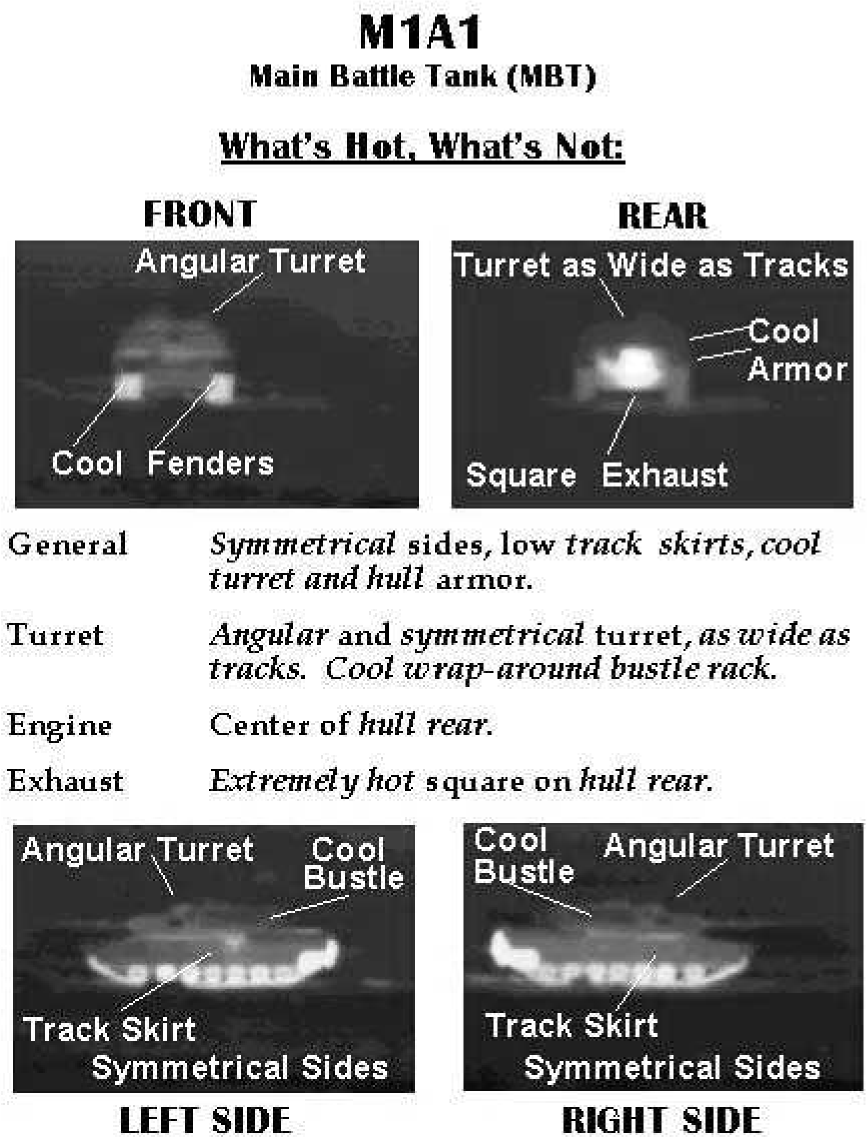

Figure 36. ROC-V Training Screen – An M1A1 in Thermal View [From: Ref. 19]

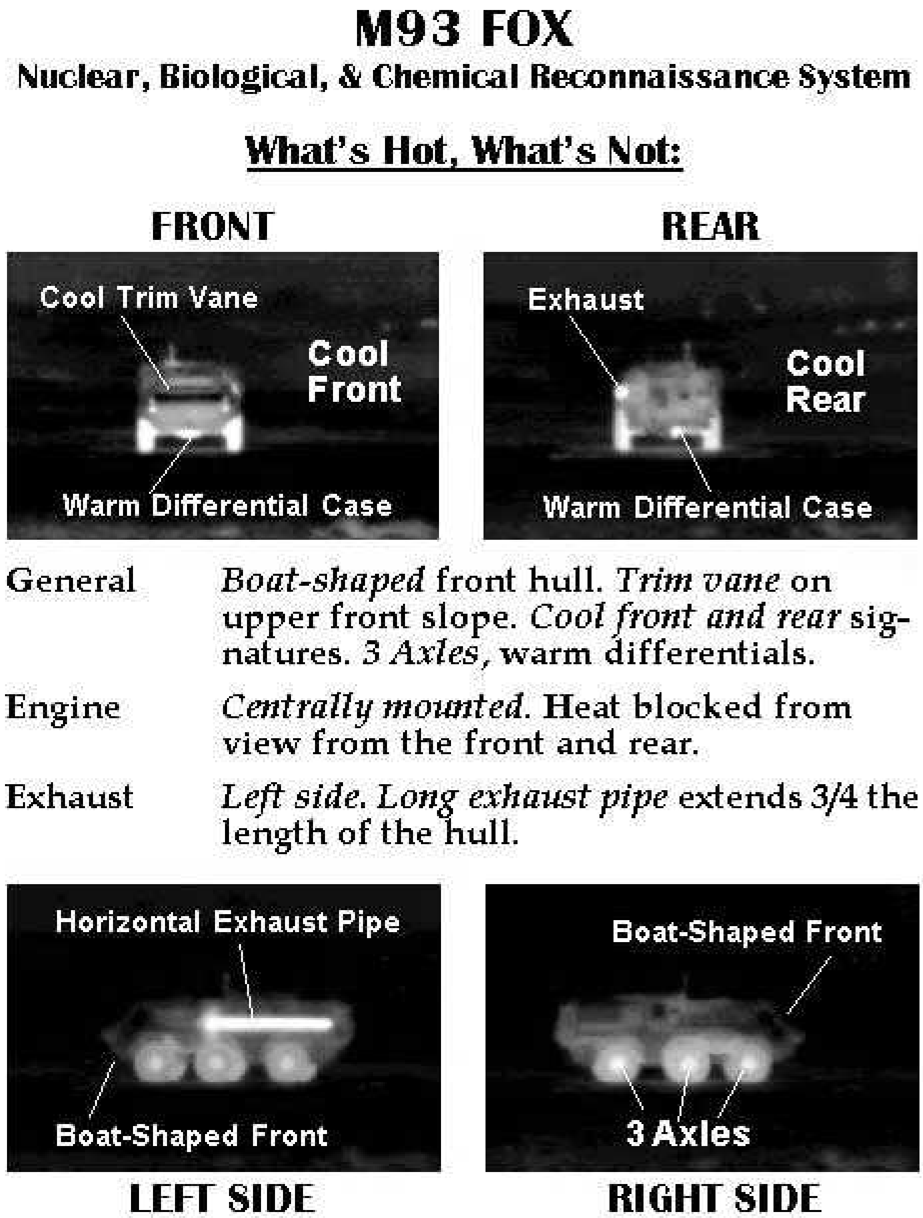

Figure 37. ROC-V Training Screen – An M93 in Thermal View [From: Ref. 19]

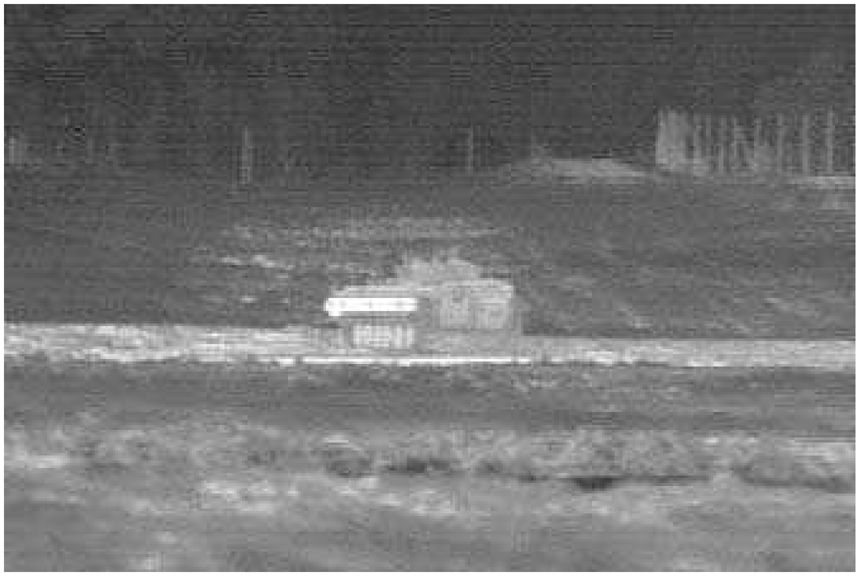

Figure 38. Shot of ROC-V Testing Screen [From: Ref. 19]

3. Incorporate the TUAV Plan Into Current Operations

The TUAV is useful to the Brigade Commander's reconnaissance, surveillance, identification, and targeting efforts – but it must be properly employed. If not synchronized with the Commander's overall plan, focus will be lost as the AV is dynamically retasked around the battlefield [Ref. 20]. The TUAV system's integration into the overall tactical plan must correlate with the Commander's Intent and TOC personnel must ensure that in the absence of the Commander, they know and adhere to his guidance regarding the TUAVs employment. Retasking an AV currently monitoring what has been identified as a critical Named Area of Interest (NAI) or High Value Target (HVT) to investigate an unknown MTI may be counterproductive to the overall mission. If the MTI is deep, the AV can be tasked later (while the wide area sensor continues to track it) or a new AV launched to investigate. Of course, the MTI may be along a route the Commander or S2 considers a likely enemy main avenue of approach and retasking the AV makes sense within the current plan. Bottomline, someone at the TOC has to be intimately familiar with the overall plan and make the call on where to prioritize the TUAV assets at any given moment.

4. Reduce the Role of "The Man in the Loop" Through SAR/ATR

One thing should be clear by this point – it does not matter how good the resolution is on a UAV, a "man in the loop" has to look at the imagery, analyze it, and make a decision on what type of vehicle it is that he is seeing. If we can reduce/remove the role of the man in the loop in the CID process, it will both decrease decision time and increase likelihood of making the correct CID call. A TUAV payload that incorporates a SAR, which is one of the future payloads being designed for the TUAV, combined with an ATR system at the GCS, could provide this solution in the near future.

Sandia National Laboratories, a national multiprogram lab working primarily in national defense research and development, advertises that their SAR Automatic Recognition Systems can "rapidly and reliably identify time critical military targets in SAR imagery" [Ref. 21]. In Sandia's algorithm development phase, the expected appearance of target vehicles in SAR imagery are modeled from available data. The degree of variation expected in the different types of targets is also quantified. Match metrics gauge the level of agreement between target models and unknown objects in new SAR imagery. The metrics, derived from mathematical principles, are designed to perform well in the presence of target signature variabilities arising from diverse sources such as rotating target parts, changing background surfaces and vegetation, partial target obscuration, and attempts at camouflage, concealment, and deception.

An independent evaluation of Sandia's ATR system's effectiveness was made during the Air Force's Expeditionary Force Experiment '98 (EFX '98), an exercise designed to test current, developing, and emerging technologies, and explore new operational concepts. The Joint Test Force report stated the following:

> This test proved the feasibility of real-time ATR on Joint STARS…in the JTF's opinion, the ID accuracy and false alarm rate are extremely encouraging.…

Figures 39 and 40 display ATR results as seen on a workstation using VITec ELT. Objects were detected using SAR, compared with signatures in the database (and signature variability accounted for), and identification of the vehicle types annotated on the workstation.

As discussed in the conclusions section, a question still remains regarding the degree of automation an ATR system should be allowed. Should we allow a proven ATR system of the future to autonomously decide whether a target is friendly or foe? Assuming we do, should we allow the ATR system to send firing instructions to weapons systems tied into it, such as AFATDS, if the ATR system identifies a target as a "hostile"?

My answer to this question is no. While allowing the system this degree of decision-making power would undoubtedly reduce target engagement times, especially in the case of critically close targets with short-duration engagement windows, the fact remains that one digital snag could mean a lot of dead soldiers on the battlefield.

Instead of allowing the ATR system total autonomy, use ATR to cue analysts and decision-makers to those targets on a cluttered battlefield that are most likely enemy. In effect the ATR system would be an "aided" target recognition system, rather than an automatic target recognition system, allowing enemy systems to be identified quicker and going further, to prioritize those that are the biggest threat to the Brigade's assets so that these priority targets can be engaged first. In this way, rather than passing responsibility for our soldiers lives to a system, we can use ATR to accomplish two tasks. First, aid the TUAV "man in the loop" by providing him with an automated CID tool to supplement his own knowledge base. Second, Brigade's can make quicker decisions on time critical targets than they are currently able using manual CID.

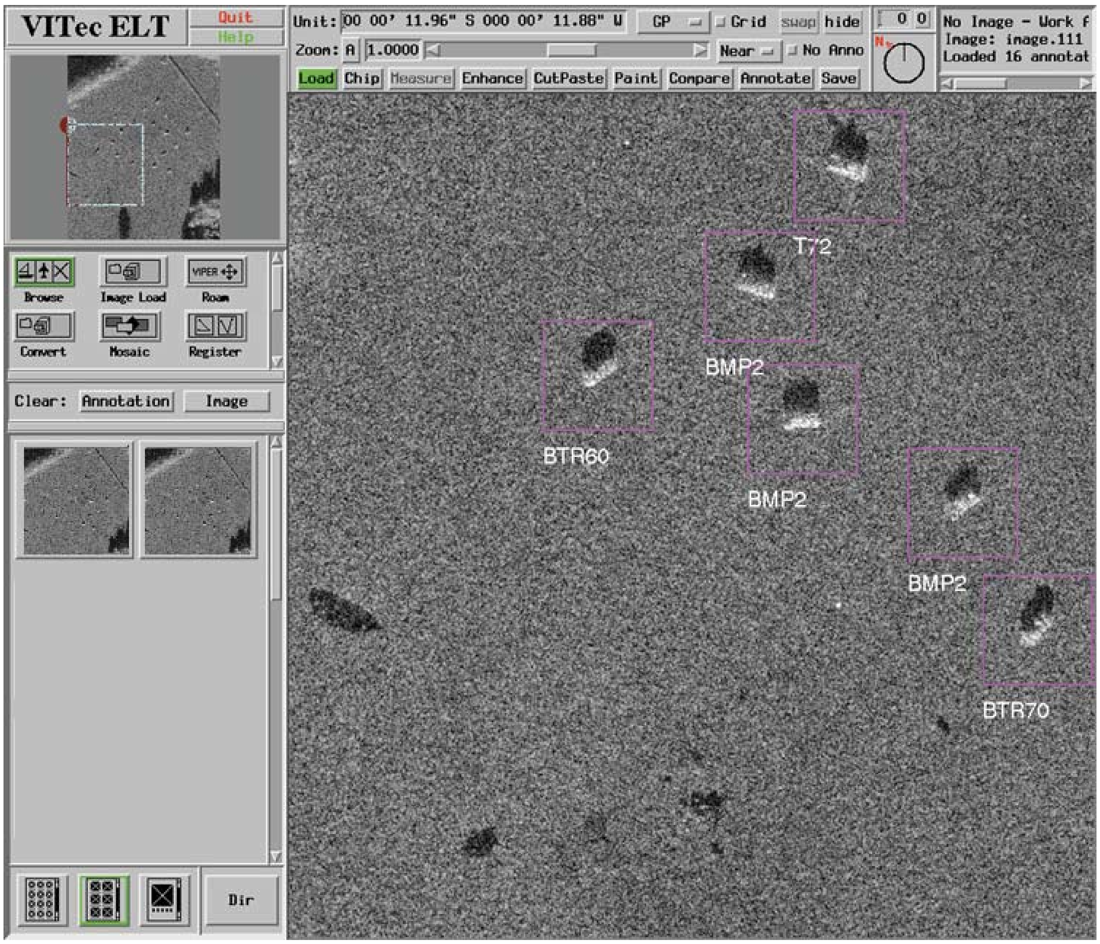

Figure 39. Sandia SAR ATR System – Wide View [From: Ref. 21]

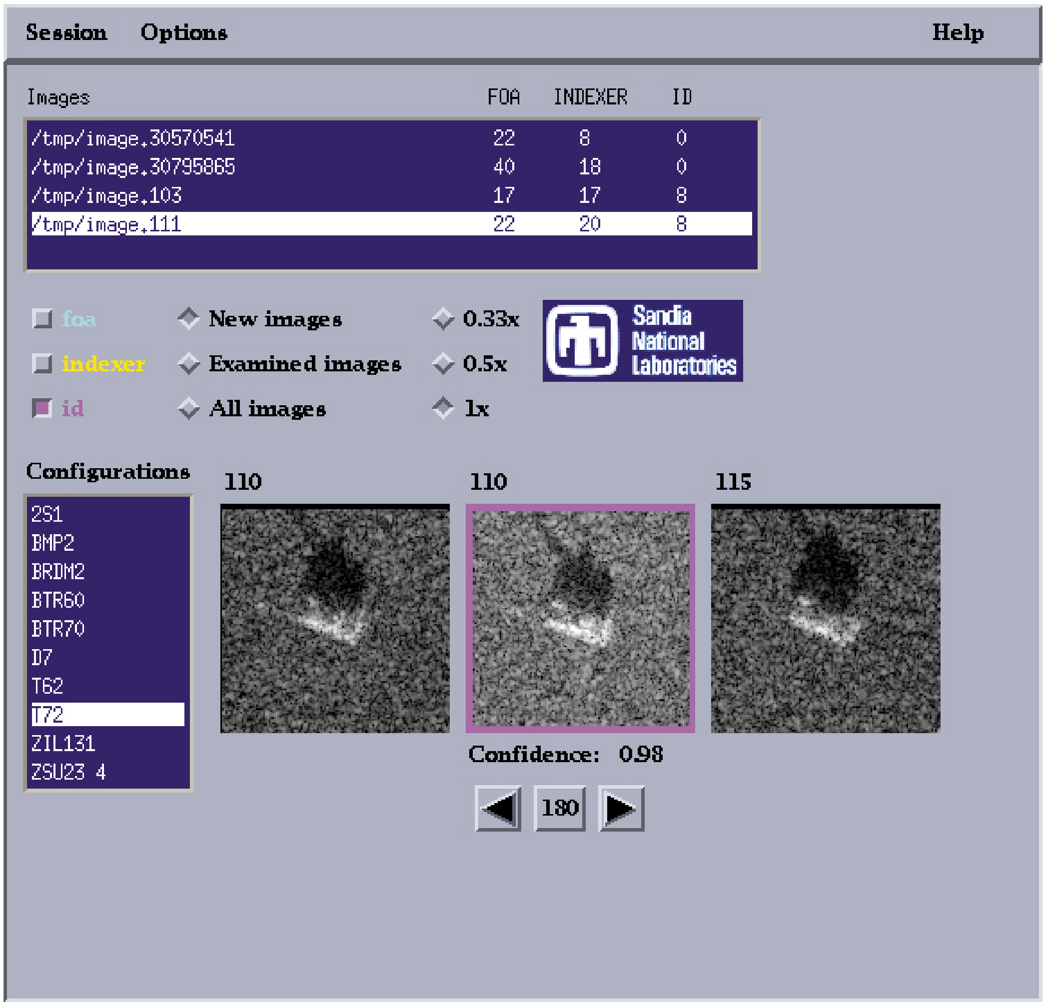

Figure 40. Sandia SAR ATR System – Index View of Individual Targets [From: Ref. 21]

5. Standardize Imagery Reporting Procedures Within the Brigades

As noted in the JCIET 2000 evaluation, if imagery reporting procedures are not worked out before integrating the TUAV system into Brigade operations, there is a real danger of multiple and/or contradictory report generation. Reports originating from the TUAV GCS should not present problems. The standardized procedures recommended in the TUAV Concept of Operations breaks requests for information into two types – planned and immediate. Figure 41 graphically displays the flow from the requestor through receipt of report(s).

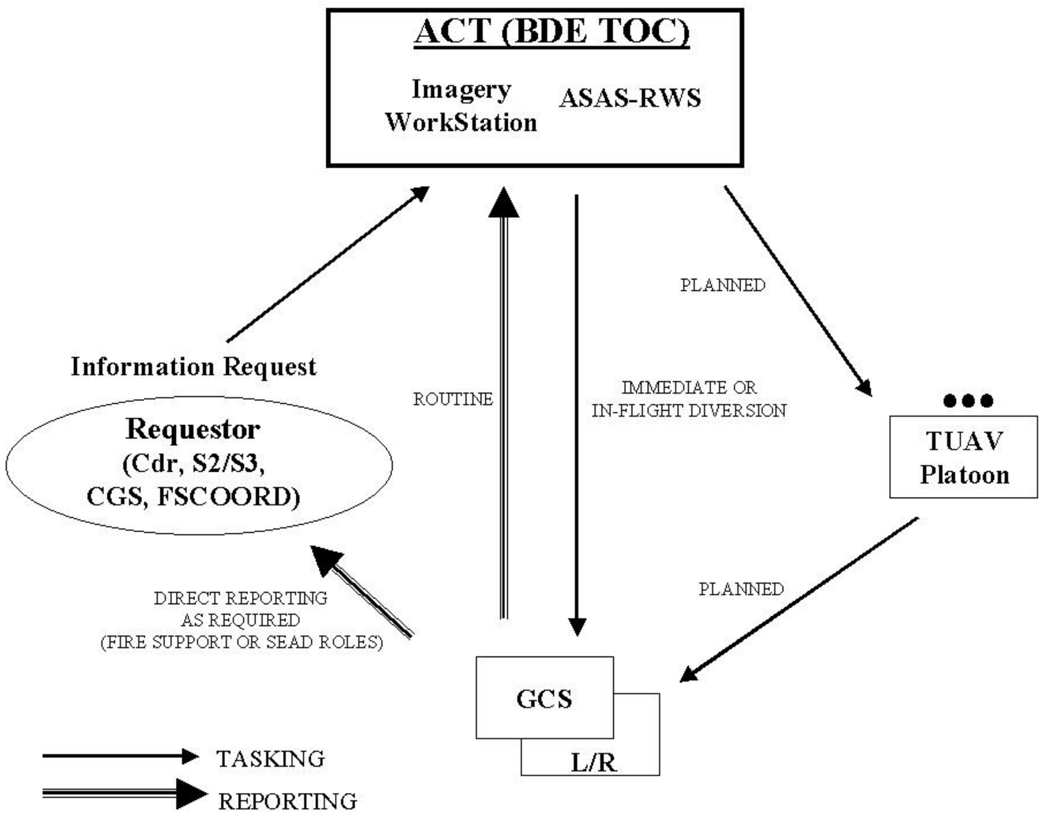

Figure 41. TUAV Tasking and Reporting [From: Ref. 8]

This standardized tasking and reporting plan significantly reduces the risk of faulty reports when the loop is requestor-GCS-requestor. The risk of multiple or contradictory reports is much higher, however, when the imagery reports are sent up from Brigade sub-units (e.g., a tank battalion headquarters that has an RVT available to it for a particular mission). The sub-units with the RVTs must supply organic personnel to man the RVT stations assigned to them. These soldiers are often untrained in imagery analyses. Additionally, imagery reporting procedures within the sub-units are often non-existent. What generally happens is someone who does not look too busy is grabbed and put into the seat as the imagery analyst.

Unfortunately, most battalion-level staffs are undermanned in order to ensure their companies and platoons are fully stocked, so this soldier is not likely to be very senior or experienced. Without proper training in both UAV imagery analyses and reporting procedures, several potential pitfalls exist – wrong (or no) identification of targets, imagery reports sent to the wrong person (or to no one), imagery reports not forwarded on the proper channel to the proper node, etc.

A solution to the training end of the problem is for battalion-level staffs to identify and train two to three personnel as UAV imagery analysts. These personnel may have other assigned duties at the Battalion TOC, but in the event that an RVT is delegated to the unit, imagery analyses becomes their primary mission. The Brigade must also develop and train an internal reporting SOP for subordinate units manning RVTs – who do the RVT analysts report to within their own units, who at Brigade receives the "refined" reports from lower echelon units, etc. Candidates at the battalion-level to filter the RVT imagery reports are the S2 (or his assistant) and the Battle Captain. This person does a quality check on the report and decides if it needs to go higher.

APPENDIX A. SCENARIO 1 SIMULATION RESULTS

This appendix displays the delays from each iteration of Scenario 1 in spreadsheet format.

Iteration 1.1 Simulation Results

Iteration	1.1
Assigned	11
Completed	7
Shot Down	1

Prep	**Point #**	**Sim Time**	**Delay**	**Total**	**Avg**
	0	22.96867	18.37182		
	1	53.16524	26.76997		
	2	70.55387	17.38863		
	3	114.6595	28.76804		
	4	133.0688	18.40927		
	5	148.6892	15.62047		
	6	175.1524	26.46319		
	7	194.8469	19.6945		
	8	219.8448	24.99791		
	9	238.2143	18.3695		
				214.8533	21.48533

Uplink	**Point #**	**Sim Time**	**Delay**	**Total**	**Avg**
	0	23.01764	0.04897		
	1	53.18583	0.020587		
	2	70.62554	0.071676		
	3	114.6956	0.036141		
	4	133.1034	0.034665		
	5	148.7026	0.013374		
	6	175.2357	0.083289		
	7	194.914	0.067095		
	8	219.9148	0.070003		
	9	238.2974	0.083053		
				0.528852	0.052885

Travel	**Point #**	**Sim Time**	**Delay**	**Total**	**Avg**
	0	33.1551	10.13746		
	1	83.1205	29.93467		
	2	111.2839	28.16336		
	3	134.804	20.10837		
	4	141.5782	6.774203		
	5	156.1724	7.469783		
	6	200.5359	25.30016		
	7	229.5482	29.01234		
	8	236.9237	7.375511		
				164.2758	18.25287

Downlink	**Point #**	**Sim Time**	**Delay**	**Total**	**Avg**
	0	84.14525	1.024749		
	1	112.5159	1.232081		
	2	135.2689	0.464927		
	3	142.0343	0.456099		
	4	156.2844	0.112055		
	5	201.9238	1.387964		
	6	230.0453	0.497109		
	7	237.7776	0.853858		
				6.028842	0.753605

Iteration 1.1 Results

Iteration 1.2 Simulation Results

Iteration	1.2				
Assigned	4				
Completed	2				
Shot Down	0				
Prep	**Point #**	**Sim Time**	**Delay**	**Total**	**Avg**
	0	38.01838	25.34179		
	1	139.8964	20.90305		
	2	237.4166	28.2315		
				74.47634	24.82545
Uplink	**Point #**	**Sim Time**	**Delay**	**Total**	**Avg**
	0	38.04614	0.027758		
	1	139.9399	0.043496		
	2	237.418	0.001392		
				0.072646	0.024215
Travel	**Point #**	**Sim Time**	**Delay**	**Total**	**Avg**
	0	60.82007	22.77393		
	1	164.1259	24.186		
				46.95993	23.47997
Downlink	**Point #**	**Sim Time**	**Delay**	**Total**	**Avg**
	0	61.93518	1.115116		
	1	164.5983	0.472424		
				1.58754	0.79377

Iteration 1.2 Results

Iteration 1.3 Simulation Results

Iteration	1.3
Assigned	9
Completed	8
Shot Down	0

Prep	Point #	Sim Time	Delay	Total	Avg
	0	31.12124	27.18676		
	1	50.99554	19.87429		
	2	71.98053	20.98499		
	3	99.14538	27.16486		
	4	128.2313	29.08589		
	5	152.2654	24.03412		
	6	180.4568	28.19139		
	7	199.8674	19.41063		
	8	229.6511	29.78368		
				225.7166	25.07962

Uplink	Point #	Sim Time	Delay	Total	Avg
	0	31.12213	0.000886		
	1	51.0593	0.063766		
	2	71.9901	0.009575		
	3	99.20459	0.059213		
	4	128.261	0.029774		
	5	152.3475	0.082085		
	6	180.4824	0.025653		
	7	199.8855	0.018086		
	8	229.6744	0.023305		
				0.312344	0.034705

Travel	Point #	Sim Time	Delay	Total	Avg
	0	42.57025	11.44812		
	1	62.31567	11.25637		
	2	77.88106	5.890958		
	3	127.4584	28.25377		
	4	137.5963	9.335285		
	5	181.0728	28.72536		
	6	194.4213	13.34848		
	7	206.1345	6.248985		
				114.5073	14.31341

Downlink	Point #	Sim Time	Delay	Total	Avg
	0	42.9768	0.406549		
	1	63.4151	1.099428		
	2	78.17986	0.2988		
	3	128.5151	1.056785		
	4	138.6702	1.073867		
	5	181.9614	0.888529		
	6	195.3254	0.904081		
	7	207.49	1.355526		
				7.083566	0.885446

Iteration 1.3 Results

Iteration 1.4 Simulation Results

Iteration	1.4
Assigned	7
Completed	6
Shot Down	0

Prep	**Point #**	**Sim Time**	**Delay**	**Total**	**Avg**
	0	75.07742	29.11772		
	1	95.65763	20.58022		
	2	122.2594	26.6018		
	3	144.412	22.15252		
	4	178.4268	28.95134		
	5	202.9541	24.52735		
	6	230.1599	27.20574		
				179.1367	25.59095

Uplink	**Point #**	**Sim Time**	**Delay**	**Total**	**Avg**
	0	75.09572	0.018304		
	1	95.68375	0.026119		
	2	122.3144	0.054957		
	3	144.479	0.067085		
	4	178.4614	0.034672		
	5	202.9825	0.028375		
	6	230.2375	0.077634		
				0.307146	0.043878

Travel	**Point #**	**Sim Time**	**Delay**	**Total**	**Avg**
	0	92.6562	17.56048		
	1	101.9429	6.259167		
	2	128.9602	6.645804		
	3	166.6495	22.17048		
	4	195.0074	16.546		
	5	227.4339	24.45137		
				93.6333	15.60555

Downlink	**Point #**	**Sim Time**	**Delay**	**Total**	**Avg**
	0	93.55167	0.895471		
	1	102.8109	0.867958		
	2	130.4087	1.448476		
	3	167.4553	0.805739		
	4	195.6374	0.630013		
	5	227.8679	0.434067		
				5.081723	0.846954

Iteration 1.4 Results

Iteration 1.5 Simulation Results

Iteration	1.5
Assigned	5
Completed	4
Shot Down	0

Prep	**Point #**	**Sim Time**	**Delay**	**Total**	**Avg**
	0	44.26951	22.00192		
	1	69.48471	25.2152		
	2	196.3932	20.37226		
	3	220.3579	20.72316		
				88.31253	22.07813

Uplink	**Point #**	**Sim Time**	**Delay**	**Total**	**Avg**
	0	44.34071	0.071203		
	1	69.54427	0.059553		
	2	196.4387	0.045529		
	3	220.3654	0.007541		
				0.183826	0.045957

Travel	**Point #**	**Sim Time**	**Delay**	**Total**	**Avg**
	0	60.49218	16.15147		
	1	76.90639	7.362122		
	2	219.0849	22.64616		
	3	235.213	14.84758		
				61.00733	15.25183

Downlink	**Point #**	**Sim Time**	**Delay**	**Total**	**Avg**
	0	61.88355	1.39137		
	1	77.56954	0.663147		
	2	220.4277	1.342822		
	3	236.4808	1.267804		
				4.665143	1.166286

Iteration 1.5 Results

Iteration 1.6 Simulation Results

Iteration	1.6
Assigned	5
Completed	4
Shot Down	1

Prep	**Point #**	**Sim Time**	**Delay**	**Total**	**Avg**
	0	48.54818	17.18853		
	1	66.75514	18.20697		
	2	85.46187	18.70673		
	3	128.0436	18.04586		
	4	224.6608	15.82384		
				87.97193	17.59439

Uplink	**Point #**	**Sim Time**	**Delay**	**Total**	**Avg**
	0	48.61791	0.069733		
	1	66.81375	0.058613		
	2	85.52519	0.063315		
	3	128.0623	0.018753		
	4	224.7046	0.043754		
				0.254167	0.050833

Travel	**Point #**	**Sim Time**	**Delay**	**Total**	**Avg**
	0	55.19897	6.581063		
	1	86.40889	19.59513		
	2	91.82189	5.413005		
	3	139.1114	11.04907		
	4	232.0804	7.375825		
				50.01409	10.00282

Downlink	**Point #**	**Sim Time**	**Delay**	**Total**	**Avg**
	0	55.33894	0.139971		
	1	86.67574	0.266853		
	2	139.8786	0.767207		
	3	233.0687	0.988309		
				2.16234	0.540585

Iteration 1.6 Results

Iteration 1.7 Simulation Results

Iteration	1.7
Assigned	10
Completed	8
Shot Down	1

Prep	Point #	Sim Time	Delay	Total	Avg
	0	51.34759	25.55481		
	1	77.32079	25.9732		
	2	96.97703	19.65625		
	3	114.9859	18.00885		
	4	144.945	29.95915		
	5	165.5059	20.56089		
	6	187.6075	22.10156		
	7	209.0747	21.46719		
	8	229.241	20.16637		
				203.4483	22.60536

Uplink	Point #	Sim Time	Delay	Total	Avg
	0	51.41115	0.063566		
	1	77.4032	0.082417		
	2	96.99662	0.019588		
	3	115.0075	0.021615		
	4	144.9544	0.009352		
	5	165.5568	0.050837		
	6	187.6687	0.061264		
	7	209.0979	0.023264		
	8	229.3022	0.061189		
				0.393093	0.043677

Travel	Point #	Sim Time	Delay	Total	Avg
	0	79.79347	28.38232		
	1	105.5991	25.8056		
	2	113.5963	7.997269		
	3	131.0735	16.06597		
	4	166.5128	21.55841		
	5	194.2096	27.6968		
	6	218.3226	24.11306		
	7	226.0555	7.732894		
	8	236.3313	7.029109		
				166.3814	18.48682

Downlink	Point #	Sim Time	Delay	Total	Avg
	0	80.39807	0.604602		
	1	105.9825	0.383473		
	2	114.5351	0.938794		
	3	166.6739	0.161108		
	4	194.3273	0.117747		
	5	219.6909	1.368222		
	6	226.925	0.869464		
	7	236.815	0.483617		
				4.927027	0.615878

Iteration 1.7 Results

Iteration 1.8 Simulation Results

Iteration	1.8
Assigned	6
Completed	5
Shot Down	0

Prep	Point #	Sim Time	Delay	Total	Avg
	0	22.57473	19.98175		
	1	47.75149	25.17676		
	2	149.5998	20.46233		
	3	175.8363	26.23645		
	4	192.8777	17.04141		
	5	216.6539	23.7762		
				132.6749	22.11248

Uplink	Point #	Sim Time	Delay	Total	Avg
	0	22.61446	0.039731		
	1	47.75836	0.006876		
	2	149.6555	0.05568		
	3	175.8428	0.006499		
	4	192.954	0.076301		
	5	216.7321	0.07827		
				0.263357	0.043893

Travel	Point #	Sim Time	Delay	Total	Avg
	0	33.52665	10.9122		
	1	69.37299	21.61463		
	2	177.5716	27.91615		
	3	198.7081	21.13647		
	4	225.9317	27.22361		
				108.8031	21.76061

Downlink	Point #	Sim Time	Delay	Total	Avg
	0	34.21	0.683345		
	1	70.35868	0.985684		
	2	178.6726	1.100967		
	3	199.4633	0.755156		
	4	226.5513	0.619585		
				4.144737	0.828947

Iteration 1.8 Results

Iteration 1.9 Simulation Results

Iteration	1.9
Assigned	9
Completed	7
Shot Down	1

Prep	**Point #**	**Sim Time**	**Delay**	**Total**	**Avg**
	0	18.68417	15.48856		
	1	34.35075	15.66658		
	2	62.95216	28.6014		
	3	89.75829	26.80614		
	4	117.9069	28.14863		
	5	138.8954	20.9885		
	6	161.0878	22.19243		
	7	203.6986	29.63718		
				187.5294	23.44118

Uplink	**Point #**	**Sim Time**	**Delay**	**Total**	**Avg**
	0	18.75437	0.070199		
	1	34.40415	0.053395		
	2	63.0212	0.069041		
	3	89.79434	0.036044		
	4	117.9419	0.034996		
	5	138.9227	0.027304		
	6	161.1129	0.025057		
	7	203.7288	0.030231		
				0.346268	0.043283

Travel	**Point #**	**Sim Time**	**Delay**	**Total**	**Avg**
	0	47.82399	29.06962		
	1	74.33282	26.50883		
	2	91.31902	16.9862		
	3	96.782	5.462979		
	4	145.8465	27.90462		
	5	165.0162	19.16966		
	6	173.7758	8.759598		
	7	223.1704	19.44158		
				153.3031	19.16289

Downlink	**Point #**	**Sim Time**	**Delay**	**Total**	**Avg**
	0	48.54451	0.720518		
	1	75.13679	0.803973		
	2	92.39617	1.077145		
	3	97.1561	0.374102		
	4	147.3146	1.468053		
	5	174.8712	1.095438		
	6	223.4747	0.304298		
				5.843527	0.83479

Iteration 1.9 Results

Iteration 1.10 Simulation Results

Iteration	1.10
Assigned	8
Completed	5
Shot Down	1

Prep	**Point #**	**Sim Time**	**Delay**	**Total**	**Avg**
	0	87.44369	23.15492		
	1	113.7103	26.26663		
	2	133.8544	20.14407		
	3	157.9479	18.50861		
	4	187.0708	29.12293		
	5	213.2202	26.14938		
	6	229.4256	16.20539		
				159.5519	22.79313

Uplink	**Point #**	**Sim Time**	**Delay**	**Total**	**Avg**
	0	87.49612	0.052436		
	1	113.7226	0.01227		
	2	133.865	0.010626		
	3	157.962	0.01414		
	4	187.1258	0.054995		
	5	213.2638	0.043627		
	6	229.4531	0.027531		
				0.215624	0.030803

Travel	**Point #**	**Sim Time**	**Delay**	**Total**	**Avg**
	0	107.7906	20.29451		
	1	119.0351	5.312536		
	2	139.7154	5.850424		
	3	184.8054	26.84334		
	4	214.0288	26.90298		
	5	232.6336	18.60485		
				103.8086	17.30144

Downlink	**Point #**	**Sim Time**	**Delay**	**Total**	**Avg**
	0	109.1461	1.355515		
	1	141.1899	1.47447		
	2	185.3738	0.568496		
	3	214.2086	0.179783		
	4	232.7613	0.12764		
				3.705904	0.741181

Iteration 1.10 Results

THIS PAGE INTENTIONALLY LEFT BLANK

APPENDIX B. SCENARIO 2 SIMULATION RESULTS

This appendix displays the delays from each iteration of Scenario 2 in spreadsheet format.

Iteration 2.1 Simulation Results

Iteration	2.1
Assigned	6
Completed	6
Shot Down	0

Prep	**Point #**	**Sim Time**	**Delay**	**Total**	**Avg**
	0	21.35531	4.305011		
	1	25.65925	1.647872		
	2	39.37413	3.689457		
	3	94.31388	3.550149		
	4	106.0646	2.070991		
	5	148.3376	3.040721		
				18.3042	3.0507

Uplink	**Point #**	**Sim Time**	**Delay**	**Total**	**Avg**
	0	21.38382	0.028504		
	1	25.6702	0.01095		
	2	39.40431	0.030187		
	3	94.36819	0.054304		
	4	106.1361	0.071497		
	5	148.3995	0.061906		
				0.257347	0.042891

Travel	**Point #**	**Sim Time**	**Delay**	**Total**	**Avg**
	0	35.51875	14.13493		
	1	42.90907	7.390327		
	2	57.05904	14.14997		
	3	123.7929	29.42468		
	4	134.7086	10.91576		
	5	167.542	19.14248		
				95.15815	15.85969

Downlink	**Point #**	**Sim Time**	**Delay**	**Total**	**Avg**
	0	35.82926	0.310515		
	1	43.19021	0.281134		
	2	58.19332	1.134274		
	3	125.2744	1.481499		
	4	135.9825	1.273844		
	5	167.9679	0.425903		
				4.907168	0.817861

Iteration 2.1 Results

Iteration 2.2 Simulation Results

Iteration	2.2
Assigned	5
Completed	5
Shot Down	0

Prep	**Point #**	**Sim Time**	**Delay**	**Total**	**Avg**
	0	52.22695	4.442963		
	1	63.93248	3.062989		
	2	67.83422	2.095876		
	3	101.5361	4.231497		
	4	114.4495	1.2672		
				15.10053	3.020105

Uplink	**Point #**	**Sim Time**	**Delay**	**Total**	**Avg**
	0	52.23992	0.012964		
	1	64.0029	0.070417		
	2	67.89395	0.059734		
	3	101.5466	0.010496		
	4	114.524	0.074437		
				0.228048	0.04561

Travel	**Point #**	**Sim Time**	**Delay**	**Total**	**Avg**
	0	79.4203	27.18038		
	1	95.59734	16.17705		
	2	110.8922	15.29482		
	3	138.998	28.10588		
	4	157.0081	18.01009		
				104.7682	20.95364

Downlink	**Point #**	**Sim Time**	**Delay**	**Total**	**Avg**
	0	80.86066	1.440362		
	1	96.80171	1.204363		
	2	111.1478	0.255684		
	3	139.9177	0.919674		
	4	158.2401	1.231928		
				5.052012	1.010402

Iteration 2.2 Result

Iteration 2.3 Simulation Results

Iteration	2.3				
Assigned	5				
Completed	5				
Shot Down	0				
Prep	**Point #**	**Sim Time**	**Delay**	**Total**	**Avg**
	0	23.12163	1.774711		
	1	44.18423	1.503708		
	2	85.56307	1.336574		
	3	111.5405	1.016534		
	4	141.6953	4.797792		
				10.42932	2.085864
Uplink	**Point #**	**Sim Time**	**Delay**	**Total**	**Avg**
	0	23.13395	0.012314		
	1	44.19778	0.013545		
	2	85.62497	0.0619		
	3	111.5875	0.04705		
	4	141.7649	0.069582		
				0.204391	0.040878
Travel	**Point #**	**Sim Time**	**Delay**	**Total**	**Avg**
	0	42.78073	19.64678		
	1	60.77304	16.57527		
	2	95.53889	9.913922		
	3	121.5618	9.974277		
	4	147.9297	6.164764		
				62.27501	12.455
Downlink	**Point #**	**Sim Time**	**Delay**	**Total**	**Avg**
	0	43.39644	0.615716		
	1	62.07182	1.298779		
	2	96.37798	0.839086		
	3	122.2599	0.698116		
	4	148.2393	0.309566		
				3.761262	0.752252

Iteration 2.3 Results

Iteration 2.4 Simulation Results

Iteration	2.4
Assigned	7
Completed	7
Shot Down	0

Prep	**Point #**	**Sim Time**	**Delay**	**Total**	**Avg**
	0	20.12909	1.335102		
	1	26.48464	4.167754		
	2	60.87004	4.973154		
	3	63.55818	2.688148		
	4	66.9995	3.441321		
	5	72.82806	1.151981		
	6	80.82186	2.629887		
				20.38735	2.912478

Uplink	**Point #**	**Sim Time**	**Delay**	**Total**	**Avg**
	0	20.17705	0.04796		
	1	26.51027	0.025627		
	2	60.92756	0.057526		
	3	63.56701	0.008831		
	4	67.05577	0.056266		
	5	72.90087	0.072816		
	6	80.90159	0.079731		
				0.348757	0.049822

Travel	**Point #**	**Sim Time**	**Delay**	**Total**	**Avg**
	0	27.42339	7.246346		
	1	36.80414	9.380747		
	2	69.86691	8.939353		
	3	98.64808	28.78117		
	4	120.155	21.50692		
	5	143.446	23.29101		
	6	153.0022	9.556199		
				108.7017	15.52882

Downlink	**Point #**	**Sim Time**	**Delay**	**Total**	**Avg**
	0	28.61627	1.192878		
	1	37.26636	0.462217		
	2	70.60352	0.736605		
	3	100.0894	1.441347		
	4	120.4336	0.278637		
	5	144.6879	1.24188		
	6	154.3698	1.367595		
				6.72116	0.960166

Iteration 2.4 Results

Iteration 2.5 Simulation Results

Iteration	2.5				
Assigned	5				
Completed	3				
Shot Down	2				
Prep	**Point #**	**Sim Time**	**Delay**	**Total**	**Avg**
	0	26.77503	2.58334		
	1	71.64464	4.782236		
	2	85.85849	2.732837		
	3	135.7451	3.669094		
	4	153.1729	1.404341		
				15.17185	3.03437
Uplink	**Point #**	**Sim Time**	**Delay**	**Total**	**Avg**
	0	26.81693	0.041901		
	1	71.71042	0.06578		
	2	85.85916	0.000671		
	3	135.8235	0.078363		
	4	153.2218	0.048891		
				0.235607	0.047121
Travel	**Point #**	**Sim Time**	**Delay**	**Total**	**Avg**
	0	56.10803	29.2911		
	1	83.11536	11.40494		
	2	111.3526	25.4934		
	3	156.9233	21.09986		
	4	169.9299	13.00663		
				100.2959	20.05919
Downlink	**Point #**	**Sim Time**	**Delay**	**Total**	**Avg**
	0	57.05361	0.945574		
	1	83.93341	0.81805		
	2	170.7833	0.853335		
				2.616959	0.87232

Iteration 2.5 Results

Iteration 2.6 Simulation Results

Iteration	2.6
Assigned	4
Completed	3
Shot Down	0

Prep	**Point #**	**Sim Time**	**Delay**	**Total**	**Avg**
	0	48.23248	3.991093		
	1	67.92474	2.608114		
	2	118.4717	1.361604		
	3	141.4658	4.218989		
				12.1798	3.04495

Uplink	**Point #**	**Sim Time**	**Delay**	**Total**	**Avg**
	0	48.27042	0.037939		
	1	68.00287	0.078124		
	2	118.5266	0.054893		
	3	141.518	0.052181		
				0.223138	0.055785

Travel	**Point #**	**Sim Time**	**Delay**	**Total**	**Avg**
	0	77.01426	28.74383		
	1	104.4694	27.45514		
	2	148.2074	29.68077		
	3	175.6154	27.40804		
				113.2878	28.32195

Downlink	**Point #**	**Sim Time**	**Delay**	**Total**	**Avg**
	0	78.33735	1.323091		
	1	105.1512	0.681818		
	2	149.1999	0.992501		
	3	176.7125	1.097048		
				4.094458	1.023614

Iteration 2.6 Results

Iteration 2.7 Simulation Results

Iteration	2.7
Assigned	3
Completed	2
Shot Down	0

Prep	**Point #**	**Sim Time**	**Delay**	**Total**	**Avg**
	0	6.946921	2.789719		
	1	146.9894	4.186207		
				6.975926	3.487963

Uplink	**Point #**	**Sim Time**	**Delay**	**Total**	**Avg**
	0	7.026087	0.079166		
	1	147.0412	0.051864		
				0.13103	0.065515

Travel	**Point #**	**Sim Time**	**Delay**	**Total**	**Avg**
	0	30.96415	23.93806		
	1	167.4417	20.40044		
				44.3385	22.16925

Downlink	**Point #**	**Sim Time**	**Delay**	**Total**	**Avg**
	0	31.58154	0.617391		
	1	167.83	0.388294		
				1.005685	0.502843

Iteration 2.7 Results

Iteration 2.8 Simulation Results

Iteration	2.8				
Assigned	3				
Completed	2				
Shot Down	1				
Prep	**Point #**	**Sim Time**	**Delay**	**Total**	**Avg**
	0	104.2704	3.528453		
	1	110.3213	4.753286		
	2	167.4095	1.419884		
				9.701624	3.233875
Uplink	**Point #**	**Sim Time**	**Delay**	**Total**	**Avg**
	0	104.3527	0.082278		
	1	110.3246	0.003299		
	2	167.4419	0.032338		
				0.117915	0.039305
Travel	**Point #**	**Sim Time**	**Delay**	**Total**	**Avg**
	0	126.9921	22.63942		
	1	137.921	10.92884		
	2	177.4553	10.01343		
				43.58169	14.52723
Downlink	**Point #**	**Sim Time**	**Delay**	**Total**	**Avg**
	0	127.3062	0.314039		
	1	138.9515	1.030513		
				1.344551	0.672276

Iteration 2.8 Results

Iteration 2.9 Simulation Results

Iteration	2.9
Assigned	6
Completed	5
Shot Down	0

Prep	**Point #**	**Sim Time**	**Delay**	**Total**	**Avg**
	0	49.66922	2.632169		
	1	58.94694	4.251344		
	2	65.56997	2.099581		
	3	96.3052	1.481551		
	4	145.3469	4.979369		
	5	174.9083	3.750866		
				19.19488	3.199147

Uplink	**Point #**	**Sim Time**	**Delay**	**Total**	**Avg**
	0	49.68222	0.013004		
	1	59.02187	0.074932		
	2	65.64239	0.072424		
	3	96.38664	0.081439		
	4	145.3559	0.009029		
	5	174.9399	0.031607		
				0.282434	0.047072

Travel	**Point #**	**Sim Time**	**Delay**	**Total**	**Avg**
	0	66.45853	16.77631		
	1	90.98694	24.52841		
	2	101.9841	10.99711		
	3	110.5913	8.607221		
	4	162.7966	17.44066		
				78.34971	15.66994

Downlink	**Point #**	**Sim Time**	**Delay**	**Total**	**Avg**
	0	67.67048	1.211954		
	1	92.21663	1.22969		
	2	103.1183	1.134215		
	3	112.0076	1.416287		
	4	163.119	0.322385		
				5.314532	1.062906

Iteration 2.9 Results

Iteration 2.10 Simulation Results

Iteration	2.10				
Assigned	4				
Completed	3				
Shot Down	0				
Prep	**Point #**	**Sim Time**	**Delay**	**Total**	**Avg**
	0	16.97409	2.864821		
	1	47.56355	2.248004		
	2	116.6117	3.960036		
	3	169.7265	2.172498		
				11.24536	2.81134
Uplink	**Point #**	**Sim Time**	**Delay**	**Total**	**Avg**
	0	17.01204	0.037952		
	1	47.59005	0.026494		
	2	116.625	0.013381		
	3	169.7713	0.044827		
				0.122655	0.030664
Travel	**Point #**	**Sim Time**	**Delay**	**Total**	**Avg**
	0	24.24823	7.236189		
	1	61.9085	14.31845		
	2	139.0538	22.4288		
				43.98344	14.66115
Downlink	**Point #**	**Sim Time**	**Delay**	**Total**	**Avg**
	0	25.6567	1.408465		
	1	63.24514	1.336641		
	2	139.217	0.163173		
				2.908279	0.969426

Iteration 2.10 Results

THIS PAGE INTENTIONALLY LEFT BLANK

APPENDIX C. SCENARIO 3 SIMULATION RESULTS

This appendix displays the delays from each iteration of Scenario 3 in spreadsheet format.

Iteration 3.1 Simulation Results

Iteration	3.1				
Assigned	6				
Completed	5				
Shot Down	0				
Prep	**Point #**	**Sim Time**	**Delay**	**Total**	**Avg**
	0	11.88497	3.205433		
	1	27.70083	1.279255		
	2	56.1277	2.422785		
	3	93.94253	4.542094		
	4	101.496	2.907684		
	5	179.9517	2.986752		
				17.344	2.890667
Uplink	**Point #**	**Sim Time**	**Delay**	**Total**	**Avg**
	0	11.90825	0.023285		
	1	27.75786	0.057026		
	2	56.16119	0.033491		
	3	94.01771	0.075186		
	4	101.5237	0.027644		
	5	179.9638	0.012131		
				0.228763	0.038127
Travel	**Point #**	**Sim Time**	**Delay**	**Total**	**Avg**
	0	17.80864	5.900391		
	1	46.14957	18.39171		
	2	65.58319	9.422001		
	3	109.1248	15.10706		
	4	122.0703	12.94551		
				61.76668	12.35334
Downlink	**Point #**	**Sim Time**	**Delay**	**Total**	**Avg**
	0	18.05192	0.243278		
	1	46.20513	0.055561		
	2	65.61217	0.028974		
	3	109.1646	0.039849		
	4	122.2555	0.185241		
				0.552902	0.11058

Iteration 3.1 Results

Iteration 3.2 Simulation Results

Iteration	3.2
Assigned	9
Completed	8
Shot Down	1

Prep	**Point #**	**Sim Time**	**Delay**	**Total**	**Avg**
	0	3.260515	2.185356		
	1	55.89245	4.94671		
	2	65.5101	1.026086		
	3	77.19566	3.844943		
	4	96.44271	2.169597		
	5	113.4888	1.180495		
	6	131.2827	1.916507		
	7	146.2713	1.909393		
	8	161.8739	3.668526		
				22.84761	2.538624

Uplink	**Point #**	**Sim Time**	**Delay**	**Total**	**Avg**
	0	3.304586	0.044071		
	1	55.93507	0.042613		
	2	65.51976	0.009663		
	3	77.22978	0.034114		
	4	96.49827	0.055565		
	5	113.5376	0.048813		
	6	131.2963	0.013596		
	7	146.2953	0.024047		
	8	161.9008	0.026898		
				0.299379	0.033264

Travel	**Point #**	**Sim Time**	**Delay**	**Total**	**Avg**
	0	31.05535	27.75076		
	1	61.98594	6.050872		
	2	82.47701	16.95724		
	3	90.05393	7.576923		
	4	102.8782	6.37995		
	5	140.4918	26.95412		
	6	148.9235	8.431709		
	7	157.533	8.609579		
	8	176.8864	14.98561		
				123.6968	13.74409

Downlink	**Point #**	**Sim Time**	**Delay**	**Total**	**Avg**
	0	31.12852	0.073173		
	1	62.16221	0.176272		
	2	82.73664	0.259636		
	3	90.29267	0.238745		
	4	103.0095	0.131287		
	5	140.8007	0.308919		
	6	149.2045	0.281048		
	7	177.1378	0.251341		
				1.720419	0.215052

Iteration 3.2 Results

Iteration 3.3 Simulation Results

Iteration	3.3
Assigned	5
Completed	5
Shot Down	0

Prep	**Point #**	**Sim Time**	**Delay**	**Total**	**Avg**
	0	4.703636	2.465556		
	1	19.27322	1.484774		
	2	91.86153	2.266578		
	3	129.4486	4.122165		
	4	138.0197	3.502598		
				13.84167	2.768334

Uplink	**Point #**	**Sim Time**	**Delay**	**Total**	**Avg**
	0	4.760655	0.057019		
	1	19.30019	0.026966		
	2	91.87084	0.009305		
	3	129.4847	0.036095		
	4	138.0798	0.060114		
				0.1895	0.0379

Travel	**Point #**	**Sim Time**	**Delay**	**Total**	**Avg**
	0	32.92549	28.16484		
	1	39.32024	6.394744		
	2	105.6849	13.81404		
	3	140.426	10.94135		
	4	167.7564	27.33036		
				86.64533	17.32907

Downlink	**Point #**	**Sim Time**	**Delay**	**Total**	**Avg**
	0	32.94135	0.015854		
	1	39.59153	0.271297		
	2	105.8816	0.196712		
	3	140.7556	0.329536		
	4	167.9671	0.210715		
				1.024115	0.204823

Iteration 3.3 Results

Iteration 3.4 Simulation Results

Iteration	3.4				
Assigned	3				
Completed	3				
Shot Down	0				
Prep	**Point #**	**Sim Time**	**Delay**	**Total**	**Avg**
	0	7.295281	2.607273		
	1	65.34352	2.608602		
	2	146.8855	1.5601		
				6.775975	2.258658
Uplink	**Point #**	**Sim Time**	**Delay**	**Total**	**Avg**
	0	7.334292	0.039011		
	1	65.35202	0.008501		
	2	146.9095	0.024013		
				0.071525	0.023842
Travel	**Point #**	**Sim Time**	**Delay**	**Total**	**Avg**
	0	16.86369	9.529401		
	1	72.33633	6.984311		
	2	169.0304	22.12089		
				38.63461	12.8782
Downlink	**Point #**	**Sim Time**	**Delay**	**Total**	**Avg**
	0	16.9439	0.080209		
	1	72.57035	0.234025		
	2	169.1029	0.072436		
				0.38667	0.12889

Iteration 3.4 Results

Iteration 3.5 Simulation Results

Iteration	3.5				
Assigned	7				
Completed	6				
Shot Down	1				
Prep	**Point #**	**Sim Time**	**Delay**	**Total**	**Avg**
	0	16.07866	4.946016		
	1	50.57259	4.318119		
	2	92.55604	3.756371		
	3	95.55812	3.002072		
	4	106.8213	2.696624		
	5	123.1372	1.977874		
	6	127.0631	3.925837		
				24.62291	3.517559
Uplink	**Point #**	**Sim Time**	**Delay**	**Total**	**Avg**
	0	16.13328	0.054614		
	1	50.60482	0.03223		
	2	92.56005	0.004004		
	3	95.57575	0.017638		
	4	106.8601	0.038751		
	5	123.1877	0.050454		
	6	127.0789	0.015766		
				0.213458	0.030494
Travel	**Point #**	**Sim Time**	**Delay**	**Total**	**Avg**
	0	29.56342	13.43014		
	1	59.4805	8.87568		
	2	112.9206	20.36052		
	3	123.1924	10.27187		
	4	137.1979	14.00545		
	5	164.4905	27.2926		
	6	171.7667	7.276189		
				101.5124	14.50178
Downlink	**Point #**	**Sim Time**	**Delay**	**Total**	**Avg**
	0	29.74234	0.178918		
	1	59.63646	0.155963		
	2	123.2071	0.014628		
	3	137.3366	0.138746		
	4	164.5805	0.090017		
	5	172.0431	0.276426		
				0.854699	0.14245

Iteration 3.5 Results

Iteration 3.6 Simulation Results

Iteration	3.6
Assigned	10
Completed	8
Shot Down	0

Prep	Point #	Sim Time	Delay	Total	Avg
	0	6.443979	1.703215		
	1	14.14585	4.569267		
	2	16.99556	2.729135		
	3	60.43323	2.569337		
	4	89.15401	1.62701		
	5	102.9867	4.865993		
	6	106.1177	2.730118		
	7	145.8693	3.221161		
	8	151.3429	3.780704		
	9	158.0717	1.373381		
				29.16932	2.916932

Uplink	Point #	Sim Time	Delay	Total	Avg
	0	6.465059	0.021081		
	1	14.16777	0.021926		
	2	17.065	0.06944		
	3	60.44886	0.015624		
	4	89.23672	0.082705		
	5	103.0519	0.065193		
	6	106.1217	0.004012		
	7	145.8832	0.013908		
	8	151.3731	0.030203		
	9	158.1175	0.045765		
				0.369857	0.036986

Travel	Point #	Sim Time	Delay	Total	Avg
	0	30.21681	23.75175		
	1	45.17367	14.95685		
	2	70.77769	25.60402		
	3	92.00079	21.2231		
	4	102.0307	10.02991		
	5	110.2185	7.166634		
	6	122.8548	12.63628		
	7	172.1423	26.25911		
				141.6277	17.70346

Downlink	Point #	Sim Time	Delay	Total	Avg
	0	30.47368	0.256872		
	1	45.5035	0.329838		
	2	70.92658	0.148887		
	3	92.02855	0.027758		
	4	102.2102	0.179467		
	5	110.3836	0.165091		
	6	123.0819	0.227054		
	7	172.398	0.255653		
				1.590621	0.198828

Iteration 3.6 Results

Iteration 3.7 Simulation Results

Iteration	3.7				
Assigned	7				
Completed	6				
Shot Down	0				
Prep	**Point #**	**Sim Time**	**Delay**	**Total**	**Avg**
	0	58.95904	2.606691		
	1	74.84452	2.507499		
	2	98.02745	4.140515		
	3	100.4455	2.418028		
	4	120.3778	3.821264		
	5	150.1452	2.82781		
	6	157.6212	3.546166		
				21.86797	3.123996
Uplink	**Point #**	**Sim Time**	**Delay**	**Total**	**Avg**
	0	59.00701	0.04797		
	1	74.84598	0.001467		
	2	98.05594	0.028495		
	3	100.4655	0.020056		
	4	120.438	0.060286		
	5	150.2016	0.056355		
	6	157.6822	0.06098		
				0.275608	0.039373
Travel	**Point #**	**Sim Time**	**Delay**	**Total**	**Avg**
	0	64.39104	5.38403		
	1	87.56219	12.71621		
	2	104.9619	6.90597		
	3	112.0551	7.093169		
	4	144.7153	24.27728		
	5	175.0796	24.878		
				81.25466	13.54244
Downlink	**Point #**	**Sim Time**	**Delay**	**Total**	**Avg**
	0	64.66725	0.276216		
	1	87.65192	0.089733		
	2	105.0993	0.137337		
	3	112.2027	0.147646		
	4	144.8534	0.138099		
	5	175.1695	0.089954		
				0.878986	0.146498

Iteration 3.7 Results

Iteration 3.8 Simulation Results

Iteration	3.8
Assigned	5
Completed	5
Shot Down	0

Prep	**Point #**	**Sim Time**	**Delay**	**Total**	**Avg**
	0	10.91349	3.403653		
	1	34.24835	3.295978		
	2	48.37792	2.043008		
	3	86.00416	1.737119		
	4	152.0766	2.750069		
				13.22983	2.645965

Uplink	**Point #**	**Sim Time**	**Delay**	**Total**	**Avg**
	0	10.99653	0.083043		
	1	34.29973	0.05138		
	2	48.44884	0.07092		
	3	86.06459	0.060436		
	4	152.1241	0.047541		
				0.313319	0.062664

Travel	**Point #**	**Sim Time**	**Delay**	**Total**	**Avg**
	0	40.036	29.03947		
	1	69.33019	29.29419		
	2	83.48755	14.15736		
	3	95.99578	9.931186		
	4	176.1134	23.98923		
				106.4114	21.28229

Downlink	**Point #**	**Sim Time**	**Delay**	**Total**	**Avg**
	0	40.11516	0.079161		
	1	69.34782	0.017625		
	2	83.54205	0.054504		
	3	96.21105	0.215266		
	4	176.4403	0.326969		
				0.693525	0.138705

Iteration 3.8 Results

Iteration 3.9 Simulation Results

Iteration	3.9
Assigned	5
Completed	4
Shot Down	0

Prep	**Point #**	**Sim Time**	**Delay**	**Total**	**Avg**
	0	11.55067	3.245622		
	1	95.73392	3.444645		
	2	100.6935	2.646702		
	3	140.093	1.316406		
	4	174.0977	2.903964		
				13.55734	2.711468

Uplink	**Point #**	**Sim Time**	**Delay**	**Total**	**Avg**
	0	11.62261	0.071944		
	1	95.76434	0.030424		
	2	100.7086	0.015032		
	3	140.1583	0.065305		
	4	174.1142	0.016548		
				0.199252	0.03985

Travel	**Point #**	**Sim Time**	**Delay**	**Total**	**Avg**
	0	31.49005	19.86744		
	1	113.1731	17.40879		
	2	120.8882	7.715076		
	3	160.2588	20.10049		
				65.09179	16.27295

Downlink	**Point #**	**Sim Time**	**Delay**	**Total**	**Avg**
	0	31.61446	0.124416		
	1	113.5031	0.32997		
	2	121.0817	0.193444		
	3	160.5788	0.319966		
				0.967796	0.241949

Iteration 3.9 Results

Iteration 3.10 Simulation Results

Iteration	3.10
Assigned	5
Completed	5
Shot Down	0

Prep	Point #	Sim Time	Delay	Total	Avg
	0	9.418746	1.297356		
	1	13.75201	3.035209		
	2	44.68901	1.183572		
	3	97.8954	1.179711		
	4	139.2211	1.495209		
				8.191057	1.638211

Uplink	Point #	Sim Time	Delay	Total	Avg
	0	9.439156	0.020411		
	1	13.76254	0.010524		
	2	44.75771	0.068696		
	3	97.92677	0.031367		
	4	139.2227	0.001613		
				0.13261	0.026522

Travel	Point #	Sim Time	Delay	Total	Avg
	0	16.80394	7.364783		
	1	24.50607	7.702128		
	2	54.35517	9.597458		
	3	119.5904	21.66367		
	4	145.4406	6.21795		
				52.54599	10.5092

Downlink	Point #	Sim Time	Delay	Total	Avg
	0	17.08574	0.281799		
	1	24.66496	0.158893		
	2	54.41802	0.062857		
	3	119.9056	0.31519		
	4	145.6654	0.224801		
				1.043541	0.208708

Iteration 3.10 Results

THIS PAGE INTENTIONALLY LEFT BLANK

LIST OF REFERENCES

1. United States General Accounting Office, *Operation Desert Storm: Investigation of a U.S. Army Fratricide Incident*, Washington, D.C., 1995.

2. Newsletter 92-4, *Fratricide: Reducing Self-Inflicted Losses (Chapter 1, Introduction and Historical Perspective)*, Center for Army Lessons Learned, Fort Leavenworth, KS, 1992.

3. Atkinson, Rick, "Fratricide Problem Defies Decades of Efforts," *Washington Post,* p. a19, 15 April 1994.

4. Product Manager Combat Identification. [http://www.monmouth.army.mil/peoiew/pmcid/cid1.htm]. April 2001.

5. Federation of American Scientists. [http://www.fas.org/man/dod-101/sys/land/m1.htm]. April 2001.

6. Joint Service Combat Identification Evaluation Team. [http://asciet.eglin.af.mil/]. April 2001.

7. CW3 Reggie Story, Shadow 200 Doctrine and Training Briefing, 15 January 2001.

8. TRADOC System Manager - Unmanned Aerial Vehicles, *Tactical Unmanned Aerial Vehicle (TUAV) Concept of Operations (CONOPs)*, 15 January 2001.

9. Electronic Mail Message (with attached presentation) from Pete Mullowney, Director of UAV Program Development, AAI Corporation, 17 April 2001.

10. Harris Corporation News Release, *Harris Corporation's Tactical Common Data Link Design Proven Successful During Phase II Testing*, 14 February 2000.

11. L-3 Communications web site. [http://www.l-3com.com/csw/product/]. July 2001.

12. Diamond, Bob, "Concepts of Modeling and Simulation". [http://www.imaginethatinc.com/frame_simulation.html]. 2001.

13. Perkins, Charles, "Unmanned Israeli Drones Made the Difference in Kosovo Operation". [http://www.us-israel.org/jsource/US-Israel/uavnato.html]. 1999.

14. Electronic Mail Message from Steve Mecham, Joint Service Combat Identification Evaluation Team (JCIET), 15 May 2001.

15. Electronic Mail Message from Dr. Scott Ritchey, JC2ISR JT&E, 15 May 2001.

16. Electronic Mail Message (with attached .jpeg photos) from Dr. Scott Ritchey, JC2ISR JT&E, 07 December 2000.

17. DARPA Special Projects Office, MSTAR program. [http://www.darpa.mil/spo/programs/mstar.htm]. July 2001.

18. Wiener, Stephen, “Don’t Shoot! I’m Your Friend!”. [http://www.mitre.org/pubs/edge/august_98/first.htm]. August 1998.

19. Recognition of Combat Vehicle (ROC-V) Training Compact Disk, Night Vision Labs, Fort Belvoir, VA.

20. Innocenti, Charles, *“Applying the Unmanned Aerial Vehicle (UAV) to Brigade Reconnaissance and Surveillance (R&S) Operations”*, Combat Training Center Quarterly Bulletin 00-4, 2000.

21. Sandia National Laboratories, Signal and Image Processing Systems Department. [http://www.sandia.gov/atr/saratr.htm]. May 2001.

INITIAL DISTRIBUTION LIST

1. Defense Technical Information Center
Fort Belvoir, Virginia

2. Dudley Knox Library
Naval Postgraduate School
Monterey, California

3. Dr. John Osmundson
Naval Postgraduate School
Monterey, California
josmund@stl.nps.navy.mil

4. CDR (Ret) JosephWelch
Naval Postgraduate School
Monterey, California
wwelch@nps.navy.mil

5. Mr. Steve Mecham
Joint Combat Identification Evaluation Team (JCIET)
Eglin Air Force Base, Florida
steve.mecham@eglin.af.mil

6. Dr. V. Scott Ritchey
JC2ISR Joint Test and Evaluation (SAIC)
Hurlburt Field, Florida
vernon.ritchey@hurlburt.af.mil

7. LTC Douglas D. Kuehl
Program Manager, Combat Identification (PM CI)
Fort Monmouth, New Jersy
douglas.kuehl@iews.monmouth.army.mil

8. Diane Fitch
CECOM Night Vision & Electronic Sensors Directorate
Fort Belvoir, Virginia
dfitch@nvl.army.mil

9. John Sundberg
DPM, TUAV
TUAV Project Office
Redstone Arsenal, Alabama
john.sundberg@tuav.redstone.army.mil

10. Dr. Orin Marvel
Naval Postgraduate School
Monterey, California
opainc@nps.navy.mil

11. Craig L. Pritzker
Project Officer, Combat Identification
MARCORSYSCOM C4IAD
Quantico, Virginia
pritzkercl@mcsc.usmc.mil

12. CDR Osa Fitch
PMA-263
UAV Advanced Development
fitchoe@navair.navy.mil

13. CAPT L. Whitmer
Program Manager, Unmanned Air Vehicles
PMA-263
whitmerld@navair.navy.mil

14. CDR William H. Johnson
Commanding Officer
Fleet Composite Squadron SIX (VC-6)
johnsonw@vc6.navy.mil